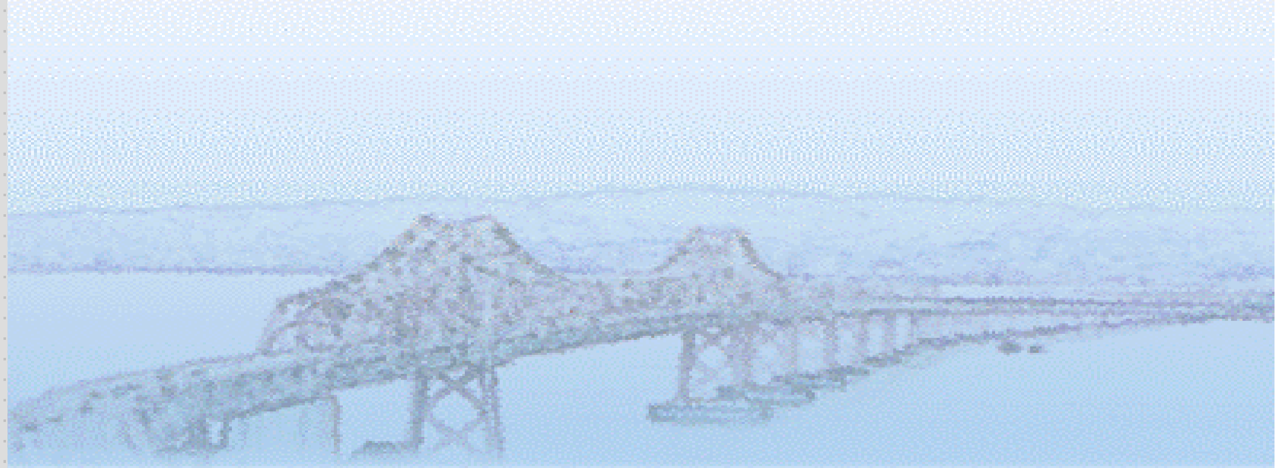
San Francisco – Oakland Bay Bridge
East Span Seismic Safety Project

Pile Installation Demonstration Project

Marine Mammal Impact Assessment



August 2001

PIDP EA 012081
Caltrans Contract 04A0148
Task Order 205.10.90 **PIDP 04-ALA-80-0.0/0.5**

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EXECUTIVE SUMMARY

This report provides an assessment of impacts to marine mammals observed during a Pile Installation Demonstration Project (PIDP) for the San Francisco-Oakland Bay Bridge (SFOBB) East Span Seismic Safety Project (East Span Project). Based on information gathered during marine mammal monitoring and noise measurements conducted during the PIDP, findings about the effectiveness of sound attenuation devices during pile driving for use in construction of the East Span Project are presented.

The PIDP was conducted in the central San Francisco Bay between October 23 and December 12, 2000 to evaluate engineering and environmental factors associated with installing large steel pipe piles that would support a replacement structure or installing piles as an element of retrofitting the existing bridge between Yerba Buena Island (YBI) and the City of Oakland. The PIDP involved driving three steel pipe piles, using two types of hydraulic hammers, one with a maximum energy rating of 500 kilojoules (kJ) (referred to as the small hammer) and one with a maximum rating of 1,700 kJ (referred to as the large hammer). Each pile had four segments, which were welded together on site. The PIDP also tested two different types of in-water sound attenuating equipment, an air bubble curtain and a proprietary fabric barrier system with an aerating mechanism, in addition to driving one pile without attenuation devices. As such, the PIDP was a demonstration project to investigate construction requirements, identify potential problems, make modifications to equipment, and examine effectiveness of sound attenuation devices for the East Span Project. Overall, the PIDP included a total of 12 hours and 51 minutes of pile driving for all segments of the piles.

Methodology

Because the PIDP could create potential disturbance to marine mammals near the project area, an Incidental Harassment Authorization (IHA) from the National Marine Fisheries Service (NMFS) was obtained. The IHA required that a safety zone be monitored for marine mammals and established a preliminary safety zone having a 500-meter (1,640-foot) radius around the pile driving site. The safety zone was to include all areas where the underwater sound pressure levels (SPLs) were anticipated to equal or exceed 190 decibels referenced to 1 microPascal, root-mean-square (190 dB re 1 μPa RMS (impulse)) (40 CFR 65 (106), June 1, 2000). Based on the actual recorded SPLs, the 190 dB contour re 1 μPa was to be identified and the safety zone was to be enlarged or reduced from the initial 500-meter (1,640-foot) zone to the 190 dB re 1 μPa contour distance. NMFS has suggested that SPLs above 190 dB re 1 μPa could cause temporary hearing impairment or threshold shifts in marine mammals, thus disrupting their behavior – a Level B harassment. According to the Marine Mammal Protection Act of 1972, Section 101(a)(5)(D), a Level B harassment is defined as a non-lethal incidental take which disturbs a marine mammal's behavioral patterns.

During scheduled days of pile driving, marine mammal monitoring was conducted at two locations: 1) within the initial 500-meter (1,640 feet) safety zone near the PIDP construction site and 2) at the YBI harbor seal haul-out site. Before pile driving of a pile segment began, NMFS-approved observers on boats surveyed the safety zone to ensure that no marine mammals were seen within the zone. If marine mammals were found within the safety zone, pile driving of the pile segment was delayed until they moved out of the area. If a marine mammal was seen above water, then dove below, pile driving was delayed up to 15 minutes and if no marine mammal was observed in that time it was assumed that the animal had moved beyond the safety zone, and pile driving resumed.

PIDP Monitoring Results

During the two-month PIDP construction period, 68 pinnipeds (55 harbor seals [*Phoca vitulina richardsi*] and 13 sea lions [*Zalopypus californianus*]) were sighted during monitoring activities. Of this total, fifty-seven pinnipeds (47 harbor seals and 10 sea lions) were seen during non-pile driving activities. Only eight harbor seals and three sea lions were observed near the PIDP site during actual pile driving, which totaled 12 hours and 51 minutes. In addition, up to 85 harbor seals per monitoring period hauled out at the semi-protected cove on the southwestern side of YBI, approximately 1,500 meters (4,920 feet) from the pile-driving area. No gray whales (*Eschrichtius robustus*) were observed. Harbor seals did not seem to be affected by pile driving noise, and typical responses included head alerts or watching the activity near the barge while swimming calmly in or out of the established 500-meter (1,640-foot) safety zone around the pile driving site. Harbor seals at YBI increased in number during low tide, and responded to activities unrelated to pile driving activities such as helicopter noise, boat traffic and kayakers, with head alerts or flushing of the site when startled or disturbed. The three sea lions seen within and beyond the 500-meter (1,640-foot) safety zone of the pile driving construction site, on the other hand, responded to pile driving noise by swimming rapidly out of the area, regardless of whether the small or large hammer was used or whether sound attenuation devices were in operation.

The underwater sound level boundary for the marine mammal safety zone was specified by the IHA as 190 dB re 1 μPa to protect marine mammal hearing and behavior. Field measurements indicated that this 190 dB re 1 μPa contour would be between 100 and 350 meters (328 and 1,148 feet) for the unattenuated pile (Pile 1) and less than 100 meters (328 feet) for the fabric barrier system with aerating mechanism. Based on the field measurements conducted, safety zones were calculated for Pile 1 without sound attenuation, Pile 2 with the air bubble curtain, and Pile 3 with the fabric barrier system with aerating mechanism. The safety zone distances for worst-case, unattenuated pile driving were calculated as 185 meters (607 feet) for a hammer energy level of 750 kJ and 285 meters (935 feet) for a hammer energy level of 1,750 kJ. Based on RMS (impulse) sound level measurements conducted on limited occasions with the air bubble curtain in place, safety zone distances for the air bubble curtain were estimated to be the same as for the unattenuated pile. The safety zone for the fabric barrier system with aerating mechanism (which consisted of an air bubble curtain plus an aerating mechanism contained within a double-layer fabric curtain) was estimated to be less than 100 meters (328 feet) for all hammer energy levels.

Conclusions

Based on marine mammal observations during the PIDP, harbor seals at the YBI haul-out site and near the PIDP site did not seem to be affected by pile driving for any of the three piles. The three sea lions observed during pile driving seemed to be affected by pile driving noise, as indicated by their swimming rapidly away from the area, during driving of both the unattenuated pile and pile with the fabric barrier system with aerating mechanism. No sea lions were noted during driving of Pile 2 with the air bubble curtain.

Gray whales may be expected in San Francisco Bay during their migration season of December through March. It is not known what their response may be as no observations of gray whales were made during the PIDP. Though their hearing is at higher frequencies than the majority of sound levels measured during driving activities, sound was generated in their hearing range. It is therefore likely that the mammals would avoid the pile driving area during construction for the East Span Project due to these higher frequency sound levels generated by pile driving, presence of equipment and consequent human disturbance (Richardson et al., 1995).

Although the limited data from the air bubble curtain measurements did not indicate a reduction in the overall linear sound level, which is the basis for the NMFS criterion, the air bubble curtain was effective at attenuating higher frequency noise in the marine mammal hearing range and resulted in a change in the impulse shape. This may be just as important to marine mammals. Although it cannot be verified based on findings of this research, the higher frequency noise attenuation provided by the air bubble curtain is likely as beneficial to marine mammals as the overall linear sound level reductions provided by the fabric barrier system with aerating mechanism.

Use of the two sound attenuation systems on the PIDP provided information about the benefits and disadvantages of each. The air bubble curtain is effective and adaptable to a seafloor with either a sloping or flat bottom. As seen at the installation of Pile 2, the air bubble curtain has a disadvantage in that fast currents in deep water may divert the air bubbles at an angle thereby reducing the effectiveness of the curtain. However, even with strong currents during the PIDP, the bubbles always surrounded Pile 2. Assembly of the bubble ring must typically be done off-site where sufficient land area is available for construction. For repeated use during the proposed East Span Project, this system could be redesigned to better withstand the pressures of being repeatedly raised to the surface. When compared to the fabric barrier system with aerating mechanism, there would be a larger economy of scale if it were designed for multiple reuse. The air bubble curtain is advantageous in that it does not need to be attached to the pile template itself, and marine construction equipment can easily maneuver around and over the site without any hindrance from the air bubble curtain. Marine construction equipment does not appear to affect the operation of the bubble curtain. For reuse, the air bubble system's lack of bulk reduces the deployment logistics of relocating it to other pile locations. Once deployed, this system requires minimal inspection. With easier deployment, maneuverability, and minimal inspection, the chances for time consuming delays would likely be decreased. For the PIDP, the bid cost was $120,000 for one installation at Pile 2.

The fabric barrier system with aerating mechanism, used at Pile 3, would be most effective in an area where a flat or consistently level bottom exists. Differences in bottom contour would result in a gap between the bottom of the curtain and the seafloor where sound would not be attenuated. For the proposed East Span Project, this system might be redesigned to be smaller for a single pile or much larger for a whole pier system. When compared with the air bubble curtain, there would be a smaller economy of scale if this system were designed for multiple reuse. Designing this system for reuse may include moving the template off-site, fitting different length curtains to it, and returning the refitted template back out to the project site. This could reduce the possibility of a gap between the bottom of the curtain and the sloping seafloor bottom. Costs would increase if the system needed to be redesigned for varying bottom elevations. Strain on the system from currents is less of a problem with this device than with the air bubble curtain alone, as the weight of the curtain typically keeps the system nearly vertical. For the PIDP, the fabric barrier system was attached to the pile template by the proprietor of the system. In future applications, this can be expected to be performed off-site. The bulkiness of this arrangement makes movement to the project site and movement between piles to be driven very difficult. The first attempt to deploy this system at the PIDP had to be postponed because in windy weather the curtain and template effectively acted as a sail. The height of this system and having it welded to the template also does not allow for easy maneuverability for the marine equipment. For example, a derrick barge cannot maneuver over it, and equipment on the barge must reach over the barrier to the pile being driven. Once deployed, this system requires inspection of the condition of the zippers in the fabric and the bottom alignment. Any damage to the fabric barrier system would likely require removing the template and barrier from the water to conduct repairs. This would cause time-consuming delays to the pile driving operations. For the PIDP, the bid plus change order cost was $580,000 for one installation at Pile 3. This included an additional bubble ring between the curtain and the pile, which was not in the project specifications, but likely aided in sound attenuation.

1.0 INTRODUCTION

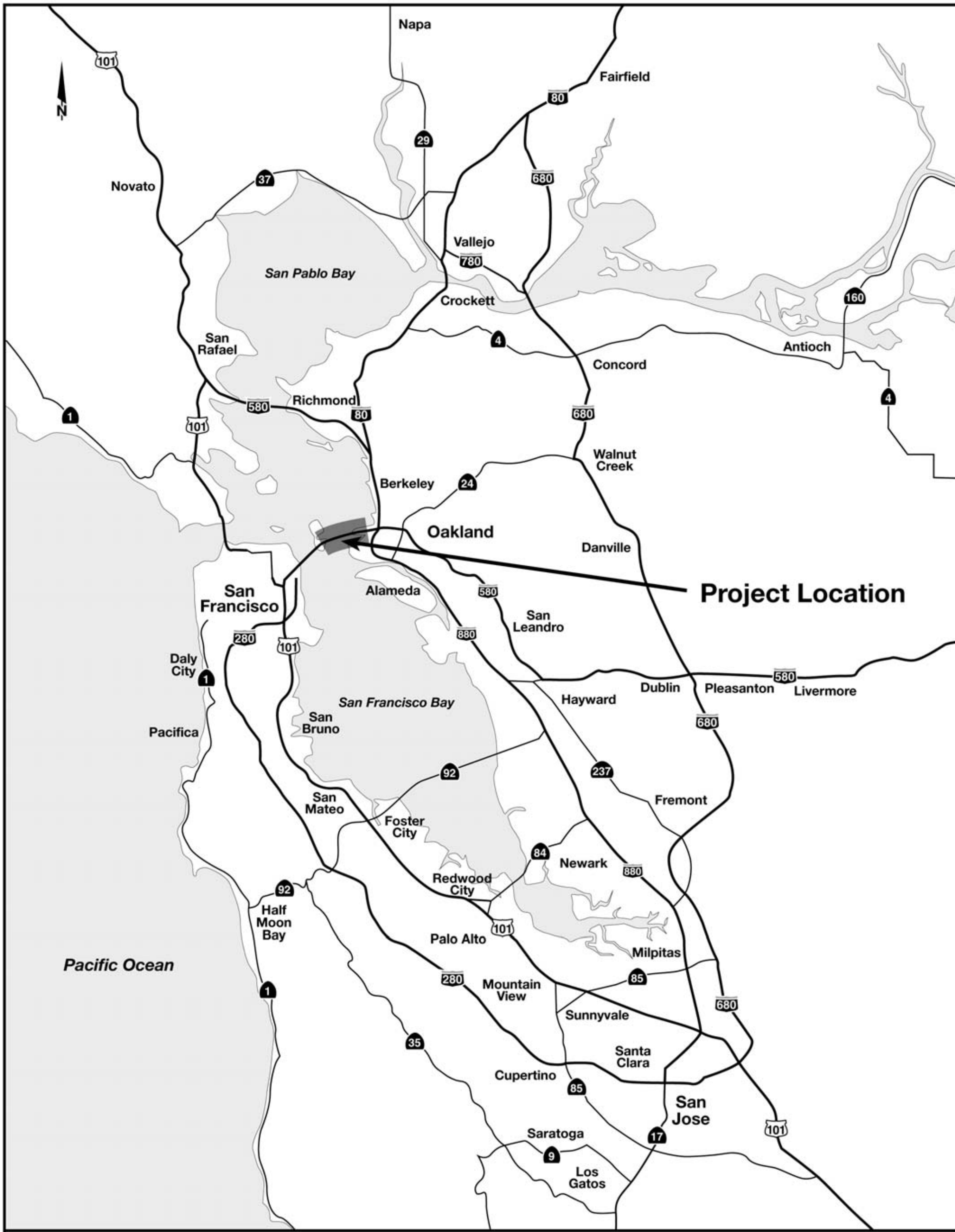
This report provides an assessment of impacts to marine mammals observed during a Pile Installation Demonstration Project (PIDP) for the San Francisco-Oakland Bay Bridge (SFOBB) East Span Seismic Safety Project (East Span Project) (Figure 1-1). Based on information gathered from marine mammal monitoring and noise measurements conducted during the PIDP, conclusions about the effectiveness of measures to reduce potential impacts to marine mammals during pile driving to construct the East Span Project are presented.

The PIDP was conducted between October 23 and December 12, 2000 to evaluate engineering and environmental factors associated with installing large steel pipe piles that would support a replacement structure or installing piles as an element of retrofitting the existing bridge between Yerba Buena Island (YBI) and the City of Oakland (Figure 1-2). The purpose of the PIDP was to identify construction restrictions, design specifications, noise impacts to marine mammals and fish, and examine effectiveness of sound attenuation devices during driving of the piles for a replacement structure or for retrofit of the existing structure.

1.1 PURPOSE OF THE STUDY

Plans for an East Span replacement structure call for increased pile size over those of the existing bridge. Effort and time to install these larger diameter piles at the project site were not known. In addition, the use of a larger, previously untested 1,700 kiloJoule (kJ) hammer was thought to be needed to drive these piles into the Young Bay Mud and Lower Alameda Alluvial Formation beneath San Francisco Bay. Part of the purpose of the PIDP, therefore, was to determine the duration of time and size of hammers necessary to drive the piles into the Bay sediment. Results of the engineering study will be used as data for the contractors bidding on the construction of the East Span Project.

Concern was also raised as to the effects of construction noise levels on marine mammals and other aquatic organisms. Marine mammals are protected under the Marine Mammal Protection Act of 1972. Harbor seals (*Phoca vitulina richardsi*) breed and forage in the Bay year-round. Twelve haul-out sites are known in the Bay, with YBI, Castro Rocks (near the east end of the Richmond Bridge) and Mowry Slough (extreme South Bay) showing greater than 40 individual harbor seals during the breeding and molting seasons (Figure 1-3). YBI is not considered a breeding site; however, pups have been occasionally observed there (Kopec and Harvey 1995). This site is particularly important during the winter, perhaps coinciding with Pacific herring populations (Spencer, 1997). Foraging areas closest to the East Span Project site include the area between YBI/Treasure Island and the Tiburon Peninsula and around the YBI haul-out site. California sea lions (*Zalopypus californianus*) are also known to forage in these areas, and haul-outs occur at Pier 39 in San Francisco (Figure 1-3).



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Scale
Kilometers 0 5 10 15 20 Kilometers

Project Location

Figure 1-1

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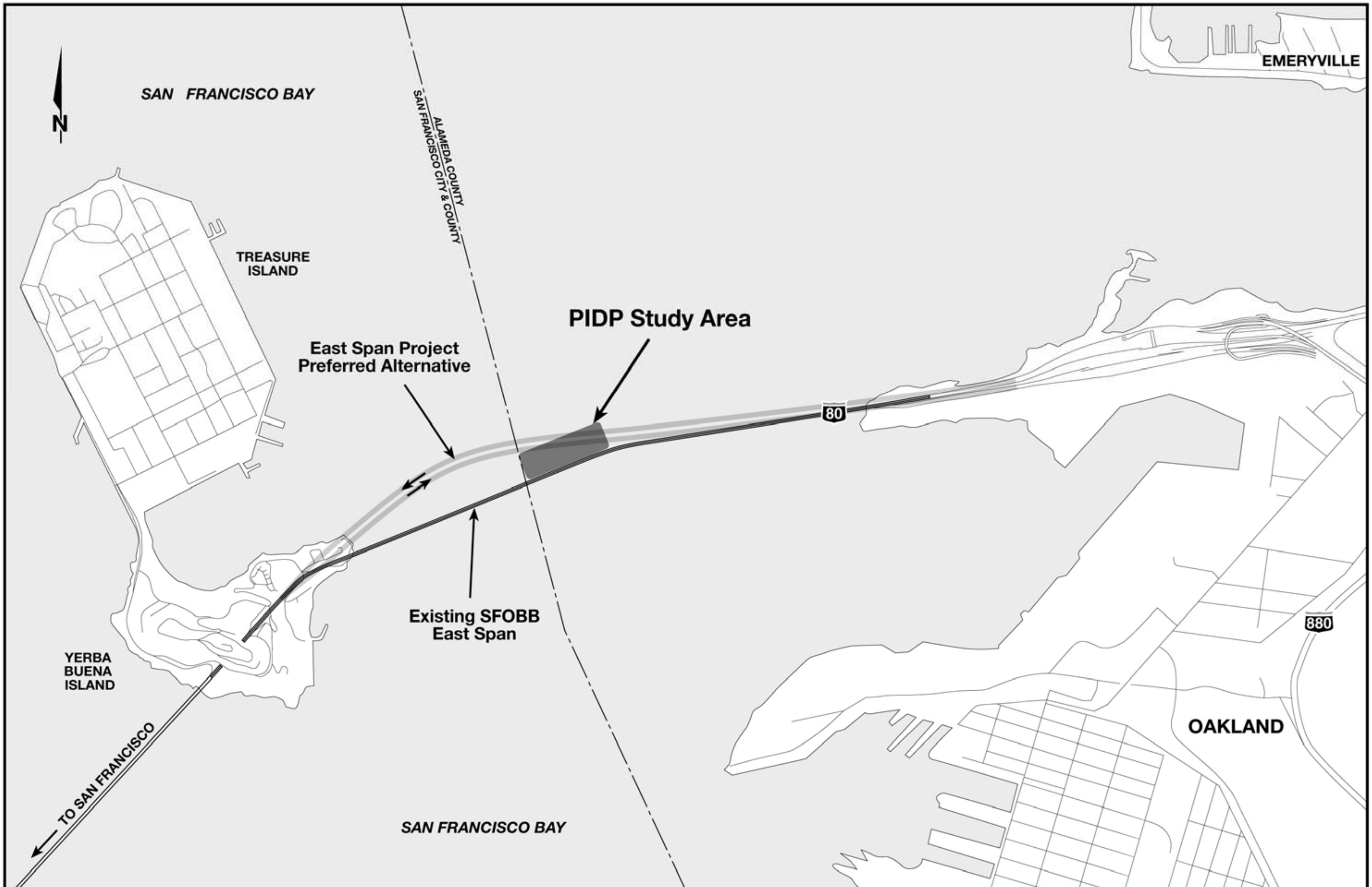

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GRAPHIC SCALE 1:27,500

0 250 500 1000 m

PIDP Study Area

Figure 1-2

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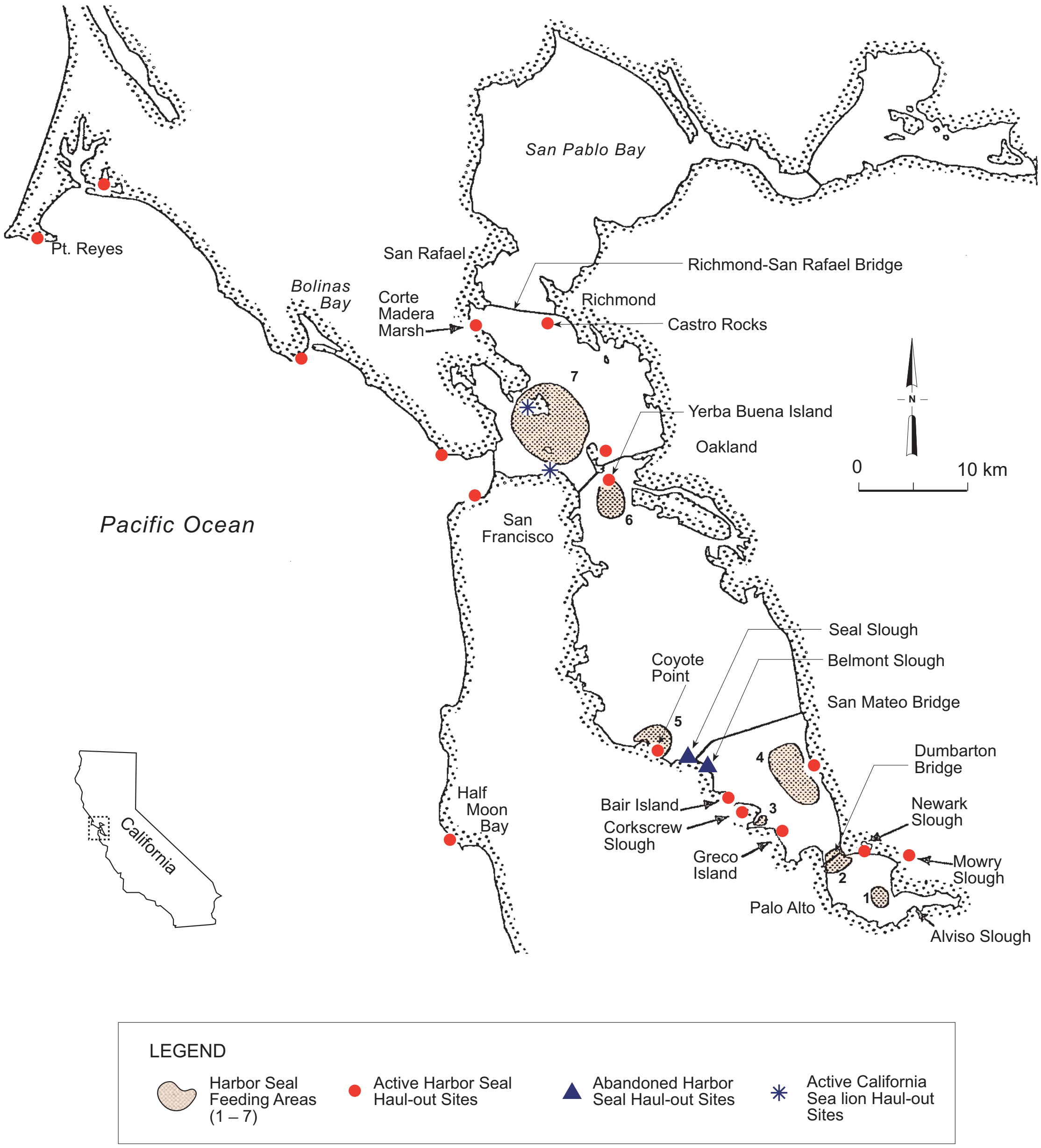


California sea lion information

Source: Goals Project (2000)

Figure 1-3 Harbor Seal and California Sea Lion Haul-out Sites and Feeding Areas in the San Francisco Bay Area

Gray whales *(Eschrichtius robustus*) have been observed with increasing frequency in recent years in San Francisco Bay. They have been sighted in the Bay during the months of December through March during their winter migration north to Alaska and the Bering Straits. Reduced food supply in the Bering Sea has been suspected as the most probable cause of their presence in the Bay Area. Sightings have been made in areas off Sausalito in Richardson Bay, the tip of the Tiburon Peninsula, and as far south as the San Bruno Shoals area. Most recently, in February 2001, a pod of gray whales was observed near the Dumbarton Bridge. Construction activities may cause hearing impairment or behavioral changes, due to pile driving noise levels at higher frequencies, presence of equipment and consequent human disturbance, if gray whales travel on either side of YBI and the project site to get to these areas. Gray whales have been observed foraging in the Bay, which is done by scraping bottom sediments for amphipods, shrimp, and other small invertebrates and sieving the muddy water mixture through baleen plates. Consumption of fish, krill and kelp has also been known to occur.

Because of potential disturbance to marine mammals due to pile driving activities, an Incidental Harassment Authorization (IHA) was obtained from the National Marine Fisheries Service (NMFS) for the non-lethal incidental take of a small number of marine mammals, pursuant to the Marine Mammal Protection Act of 1972 (MMPA) (Appendix C). In Section 101(a)(5)(D), the MMPA defines an act which results in injury to a marine mammal as a Level A harassment, while an act that disturbs a marine mammal's behavior patterns is a Level B harassment. NMFS has suggested that sound pressure levels (SPLs) above 190 decibels referenced to 1 microPascal, root-mean-square (190 dB re 1 μPa RMS (impulse)) could cause temporary hearing impairment or threshold shifts in marine mammals, thus disrupting their behavior – a Level B harassment.

The IHA indicated that a safety zone that included all areas where the underwater SPLs were anticipated to equal or exceed 190 dB re 1 μPa must be established around the pile driving work. An initial underwater safety zone of 500 meters (1,640 feet) was set until SPL measurements could be made to determine the 190 dB contour re 1μPa.

The second objective of this study was to monitor the presence of marine mammals during pile driving, report any behavior modifications of the marine mammals resulting from pile driving activities, and test sound attenuation devices for their effectiveness in reducing SPLs. Specifically, the PIDP provided an opportunity to measure resulting SPLs both in air and underwater and evaluate the effectiveness of two types of sound attenuation equipment, an air bubble curtain and a fabric barrier system with aerating mechanism. Based on the results of the marine mammal monitoring and noise measurements, safety zones for pile driving using the small and large hammers and each sound attenuation device were to be redefined from the 500-meter (1,640-feet) safety zone initially established by the IHA. The IHA also established requirements to delay to the start of pile driving if marine mammals were seen in the safety zone. Before pile driving of a pile segment began, NMFS-approved observers on boats were required to survey the PIDP safety zone to ensure that no marine mammals were found within the safety zone. If marine mammals were found within the safety zone, pile driving of the segment was to be delayed until they moved out of the area. If the observed marine mammal seen above water then dove below, pile driving was to be delayed for up to 15 minutes to allow time for marine mammal movement out of the area. If no marine mammal was observed during that time, it should be assumed that the animal has moved out of the area and pile driving could commence. If a marine mammal entered the safety zone after pile driving of a segment already began, hammering was allowed to continue unabated and marine mammal observers were to monitor and record their numbers and behavior.

1.2 PROJECT DESCRIPTION

The PIDP involved driving three piles, with two different sizes of hammers and the use of two different methods of underwater sound attenuation. The test piles, labeled 1, 2 and 3, were made of steel pipe 2.4 meters (8 feet) in diameter. Pile 1 was driven straight down and did not use any sound attenuation.

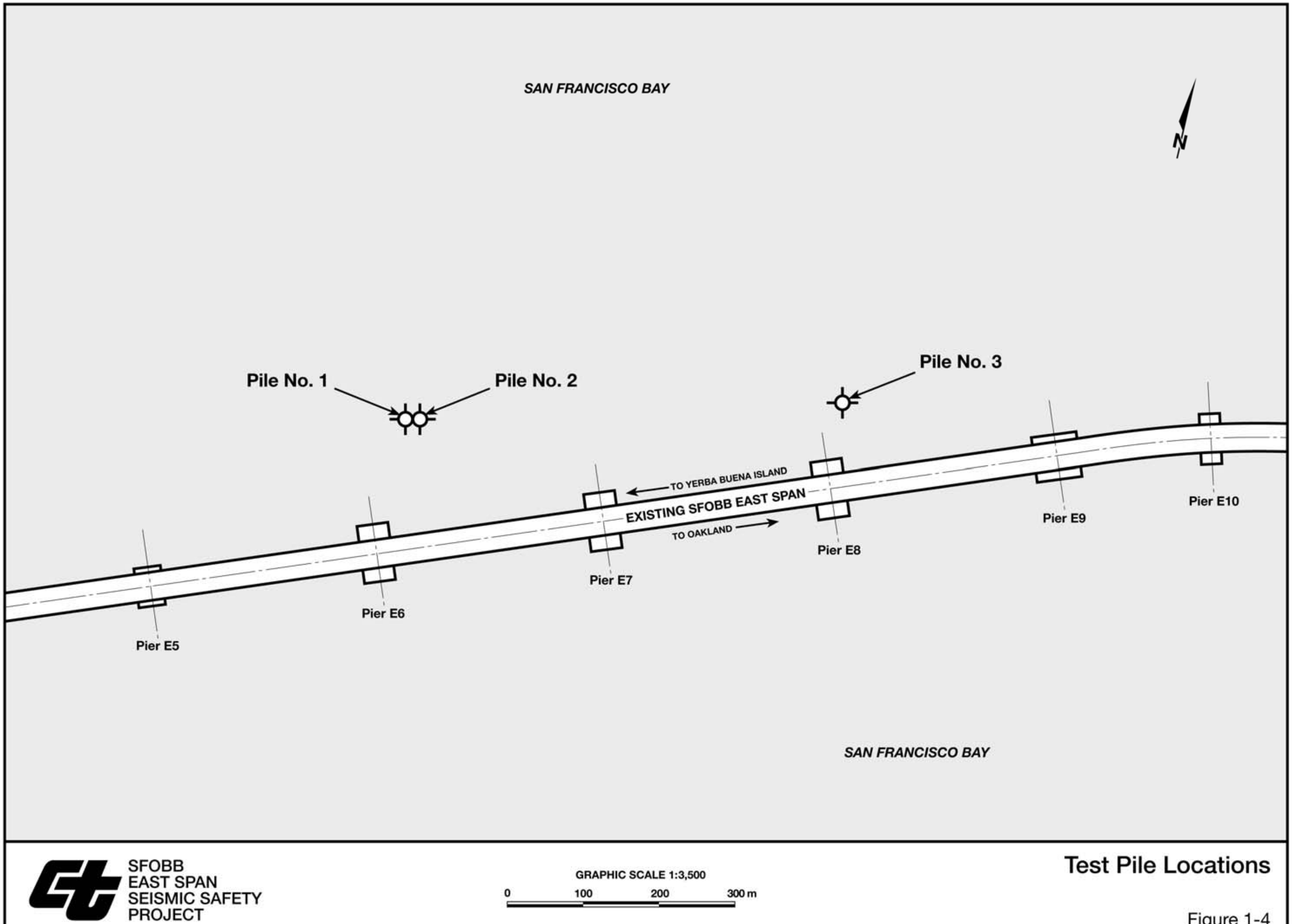
Pile 2 was a battered pile angled 1h:6v to the east and used an air bubble curtain. The air bubble curtain provides a curtain of air around the pile to attenuate noise from driving activities. Bubbles emerged from a submerged piping system that surrounded the pile template (used to hold the hammer/pile in place). The piping system was comprised of three perforated PVC pipes attached to a steel frame, forming an octagonal ring. Two rows of 0.1-centimeter (0.04-inch) holes were drilled into the PVC pipes. The bubble curtain system was fabricated and assembled off-site, then transported to the pile-driving site using a barge-mounted crane. The piping system ring was then submerged to the bay floor to encircle the pile template. Air was supplied from a 1600 cfm compressor on the barge during the driving of Pile 2. Though Pile 2 was driven at an angle, the bubbles streamed straight up to the water surface, potentially providing less attenuation near the surface than at greater depths. A similar system was used by Wursig et al. (2000) for attenuating noise received by dolphins during pile driving activities for an airport expansion.

Pile 3 was a battered pile angled 1h:6v to the west and was surrounded by a proprietary method of sound attenuation referred to as a fabric barrier system with aerating mechanism. The fabric barrier system consisted of an in-water, double-layer fabric curtain with a single aerating mechanism between the two fabric sheets, in addition to an air bubble curtain similar to the one use for Pile 2 but with smaller diameter PVC pipes adjacent to the inner fabric layer. The fabric curtain was made of water-permeable material which enclosed the pile template. The top of the curtain attached to the pile template at a level a few meters above the surface of the water. The bottom was attached with beams to the bottom of the template. This proprietary fabric barrier system with aerating mechanism was assembled and attached to the template off-site. The template/air bubble and fabric barrier was transported by barge to the Pile 3 location. Air was supplied from a 1600 cfm compressor on the barge during driving activities.

Each pile was made up of four 33-meter (108-foot)-long sections labeled Sections A-D, which were driven and welded together in succession until the full length of the pile was achieved. The first section, Section A, generally required relatively little pounding. The weight of the pile with a moderate level of pounding was enough to drive it down through the soft mud on the bottom of the Bay. Pile Sections B through D required progressively more energy to drive the piles into harder muds and soft rock. Two types of Menke hydraulic hammers were employed to drive the piles; a small hammer rated at 500 kilojoules (kJ), and a large hammer rated at 1,700 kJ. It took approximately ¾ of an hour to several hours to drive one section. There were many work stoppages to weld new sections and make measurements and repairs. The first few hammer strikes were irregular in timing and typically at a lower energy. Once all systems were operating properly, there were typically 25-30 strikes to the pile per minute. Over the two-month period between October 23 and December 12, 2000, pile driving was conducted for a total period of 12 hours and 51 minutes.

The piles were installed at two locations adjacent to the existing SFOBB East Span (Figure 1-4). Piles 1 and 2 were installed north of East Span pier E6, where the water is approximately 9 meters (30 feet) deep. Pile 3 was installed north of East Span pier E8, where the water depths range between approximately 7 meters (25 feet) to the west of the pile and 5 meters (17 feet) deep to the east of the pile. The barge from which pile driving equipment was operated was held in place next to the test pile by a system of anchors and pilings that could be adjusted as needed. Photos of the PIDP barge and the large and small hammers are shown in Figures 1-5 and 1-6. Photos of the air bubble curtain in operation and the fabric barrier system with aerating mechanism are shown in Figures 1-7 and 1-8.

During the PIDP, several monitoring efforts were undertaken to study the environmental impacts of pile driving. This report presents the results of marine mammal monitoring and noise measurements conducted during the PIDP and an evaluation of the sound attenuation devices in terms of effectiveness at reducing noise, costs, and operational/deployment difficulties for the East Span Project.



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Test Pile Locations

Figure 1-4

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Figure 1-5. PIDP Barge and Large Hammer.

Figure 1-6. PIDP Barge and Small Hammer.

Figure 1-7. Air Bubble Curtain in Operation

Figure 1-8. Fabric Barrier System with Aerating Mechanism (lower right corner of figure).

2.0 METHODOLOGY

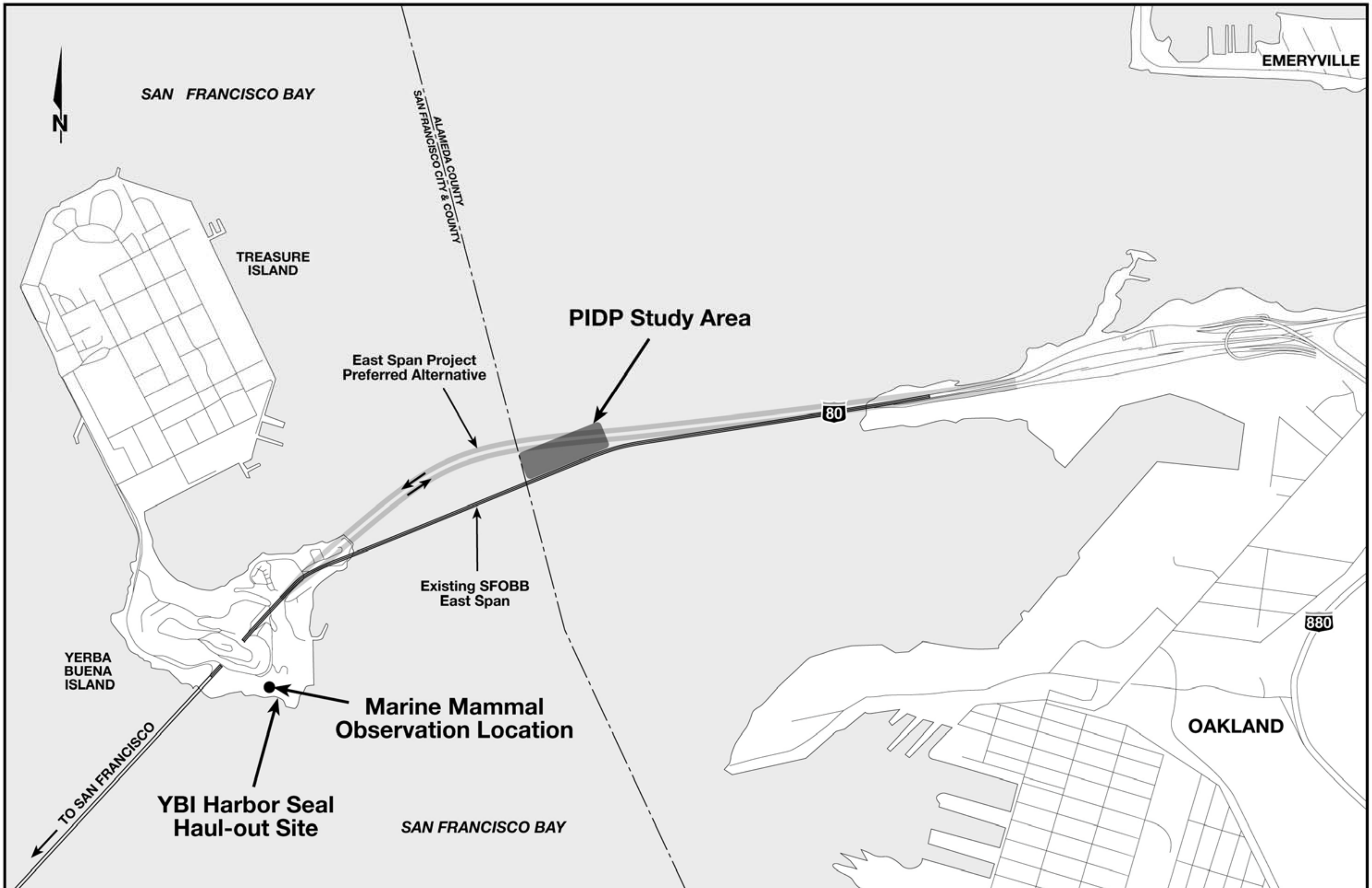
2.1 MARINE MAMMAL MONITORING

The marine mammal monitoring team consisted of marine biologists who were approved by NMFS as required by the IHA (Appendix C). Observations were conducted on three days prior to construction at the PIDP construction site and YBI, and each day of pile driving activity. During scheduled days of pile driving, marine mammal monitoring was conducted at two locations: 1) within the initial 500-meter (1,640 foot) safety zone near the PIDP construction site and 2) at the YBI haul-out site, a semi-protected cove on the southwestern side of the island approximately 1,500 meters (4,920 feet) from and out of the direct line-of-site of the PIDP site. Monitoring of each area began at a minimum of 30 minutes before pile driving began, and ended approximately 30 minutes after completion of the pile driving. Bay conditions, tide level, boat traffic, temperature, wind speed and direction, and other environmental parameters were noted on each monitoring day. Demographic information (number and species present, age class, presence of red pelage, gender, behavior and identifying marks) and details of any disturbances were also recorded.

At least two observers conducted observations at the YBI haul-out site using binoculars from a bluff above the haul-out area (see Figure 2-1) to see if disturbance to the harbor seals below was observed, and what conditions were present at the time of the disturbance. Communication was conducted via radio between the observer, program manager and contractor as necessary to report any marine mammal in the safety zone.

Near the project site, a total of at least three observers conducted observations from a small inflatable craft, the main monitoring boat, the construction barge, and the SFOBB piers (Figure 2-2). Observations were conducted between piers E6 and E9 of the SFOBB East Span. During the driving of Piles 1 and 2, observers were stationed on pier E7 (150 meters [492 feet] east of the pile driving barge), on the north end of the pile driving barge, in a 4 meter (13 foot) inflatable boat anchored 300 meters (984 feet) north of the barge, and on the monitoring boat typically moored 150 meters (492 feet) southwest of the barge. Observers for Pile 3 were stationed on the barge, on the monitoring boat, and piers E6 and E9. This provided 360 degrees of observation area.

Initial scanning of the safety zone was without binoculars. High-resolution binoculars and a spotting scope were used once a marine mammal was seen to determine species, age class, pelage color and behavior of any sighted seals or sea lions. Observations were recorded in a data book using a compass to determine the position of the pinnipeds. Videotaping and 35mm cameras were also used to document the behavior and response to any disturbances.



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GRAPHIC SCALE 1:27,500

0 250 500 1000 m

Marine Mammal Observation Locations at Yerba Buena Island

Figure 2-1

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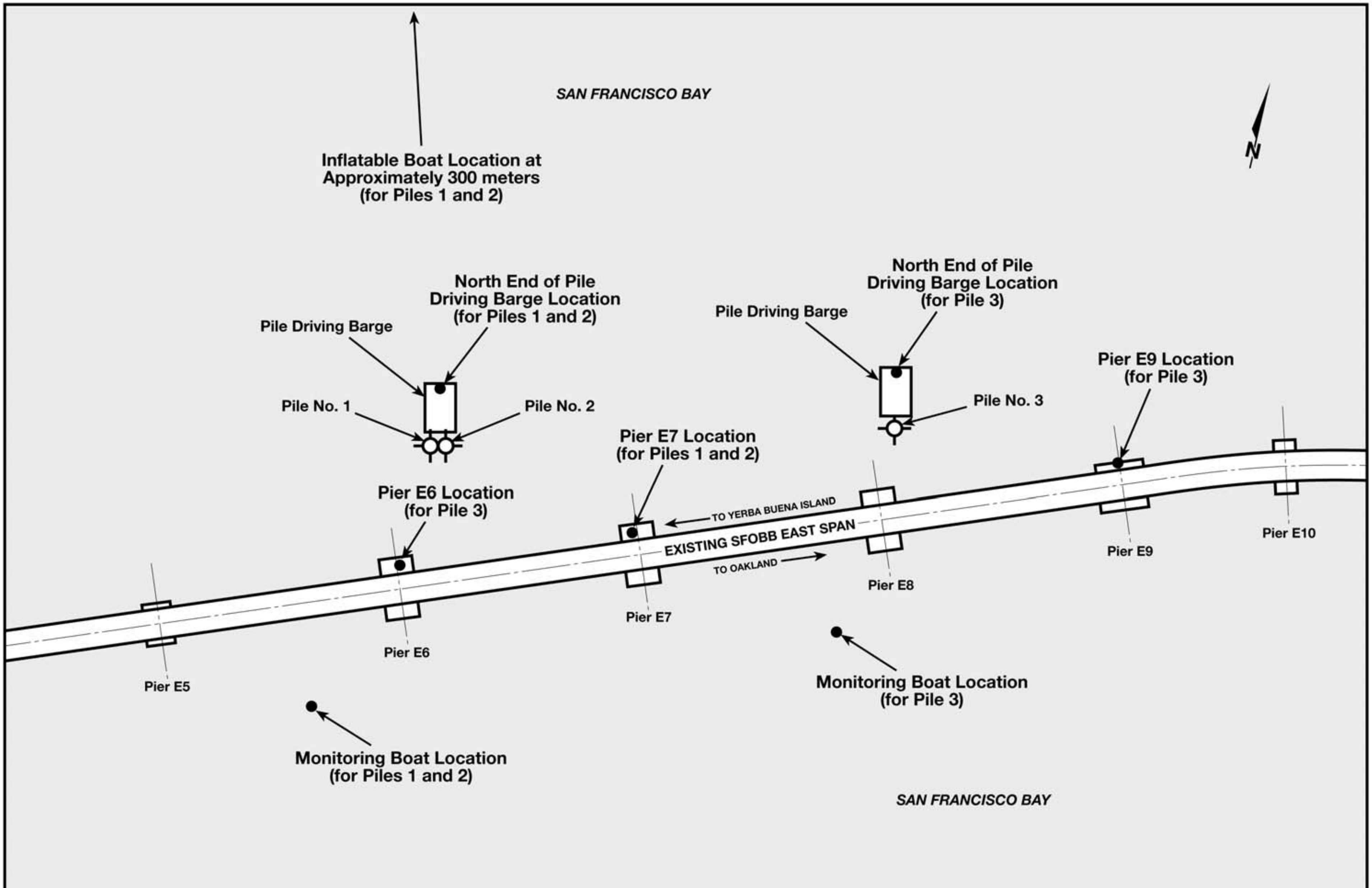

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GRAPHIC SCALE 1:3,500

0 100 200 300 m

Marine Mammal Observation Locations at Pile Driving Site

Figure 2-2

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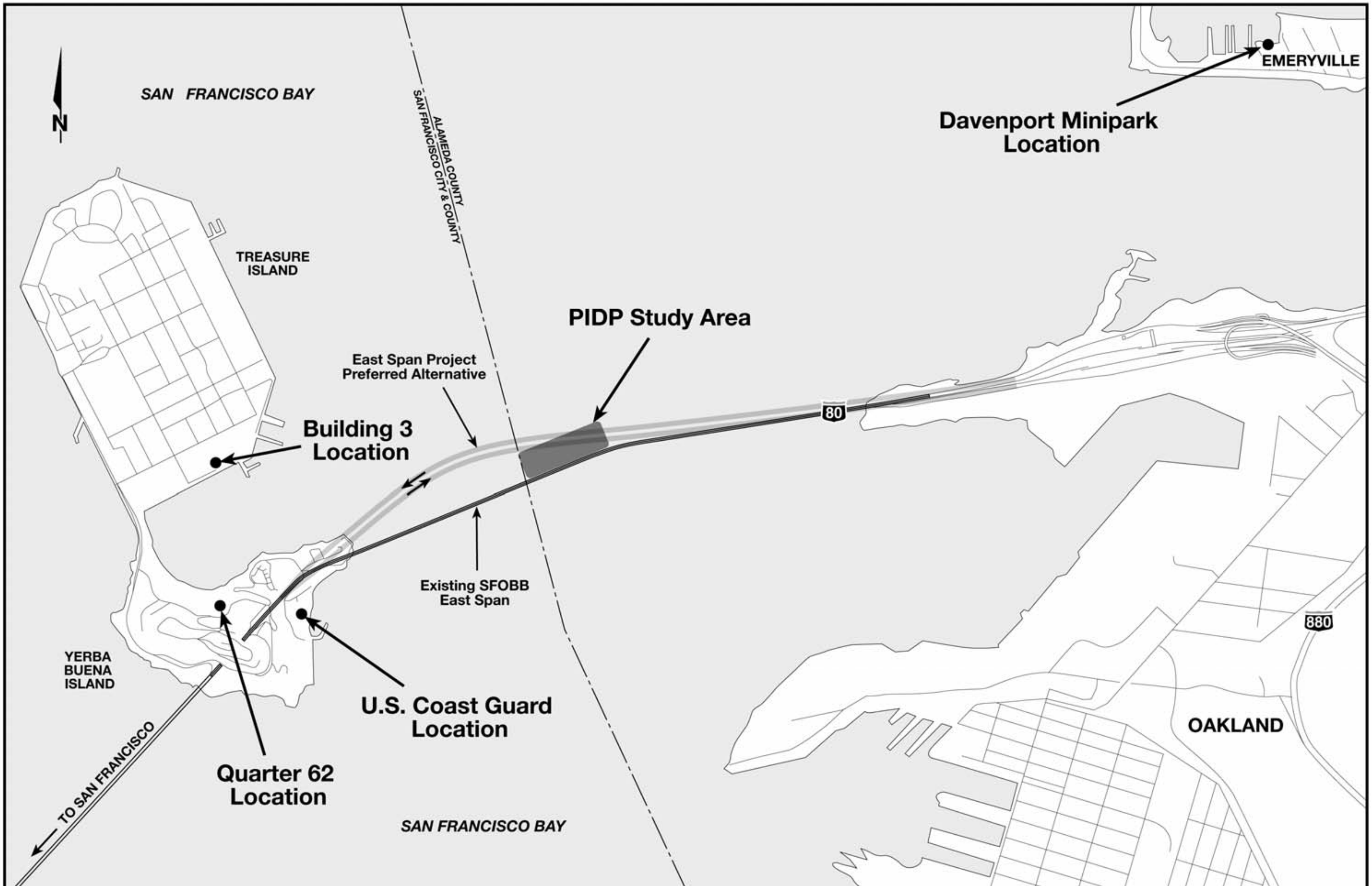
Based on the specifications in the IHA, if a marine mammal was observed in the 500-meter (1,640-foot) safety zone before pile driving began, pile driving would be delayed until the marine mammal moved out of the area. If a marine mammal was seen above water and then dived below, pile driving would be delayed for up to 15 minutes and if no marine mammals were observed in that time, it was assumed that the animal had moved out of the area and pile driving resumed. If a marine mammal entered the safety zone after pile driving of a segment already began, hammering was allowed to continue unabated and marine mammal observers monitored and recorded their numbers and behavior.

2.2 NOISE MEASUREMENTS

During the PIDP, a sound monitoring team measured airborne and underwater noise levels at various locations in the project vicinity. Airborne noise levels were not available at the YBI haul-out site. Airborne noise levels were measured at four (4) distant locations on YBI, Treasure Island and Emeryville. Airborne noise measurements taken at the US Coast Guard (USCG) Bachelor Enlisted Quarters (BEQ) on YBI and at Building 3 on Treasure Island are presented in this report to represent the worst-case noise levels at the YBI haul-out site (Figure 2-3). Comparability of the airborne YBI and Treasure Island data to the close-in data is limited, however, as the former locations were determined for human disturbance and therefore measured in units related or referenced to human reception, and not applicable to marine mammals. Ambient airborne noise would also be different at the distant and close-in locations and comparison of increases from these levels would be difficult. Airborne and underwater noise at close-in locations to the pile-driving barge were also measured at one to three distances from the barge, primarily during the driving of the last section of the piles (Section D) when the large hammer was used (Figure 2-4). As close-in measurements of airborne and underwater noise were made at a limited number of distances, the 190 dB contour re 1μPa for each hammer and attenuation device was not necessarily captured. Therefore, the marine mammal safety zone for Pile 1 without sound attenuation, Pile 2 with the air bubble curtain, and Pile 3 with the fabric barrier system and aerating mechanism were calculated based on available data. The details of this analysis are presented as Appendix D.

SPLs for airborne and underwater noise were measured and reported in several different units of measurement. Data in this report are presented in linear peak for airborne noise measurements, and both linear peak and RMS (impulse) for underwater noise measurements. The linear peak sound level indicates the maximum instantaneous SPL during the pile-driving period and is the highest SPL within that period that may be damaging to marine mammals. RMS (impulse) is the unit requested and reported by NMFS to identify the underwater safety zone, and is typically the maximum SPL in water averaged over the duration of the impulse, but in this study, a 1/32 second (31 milliseconds) time constant was used. This value represents the time over which most of the impulse energy specific to this study occurred for a more conservative estimate of the NMFS criterion (for further detail see Appendix A and D).



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GRAPHIC SCALE 1:27,500

0 250 500 1000 m

Distant Airborne Noise Measurement Locations

Figure 2-3

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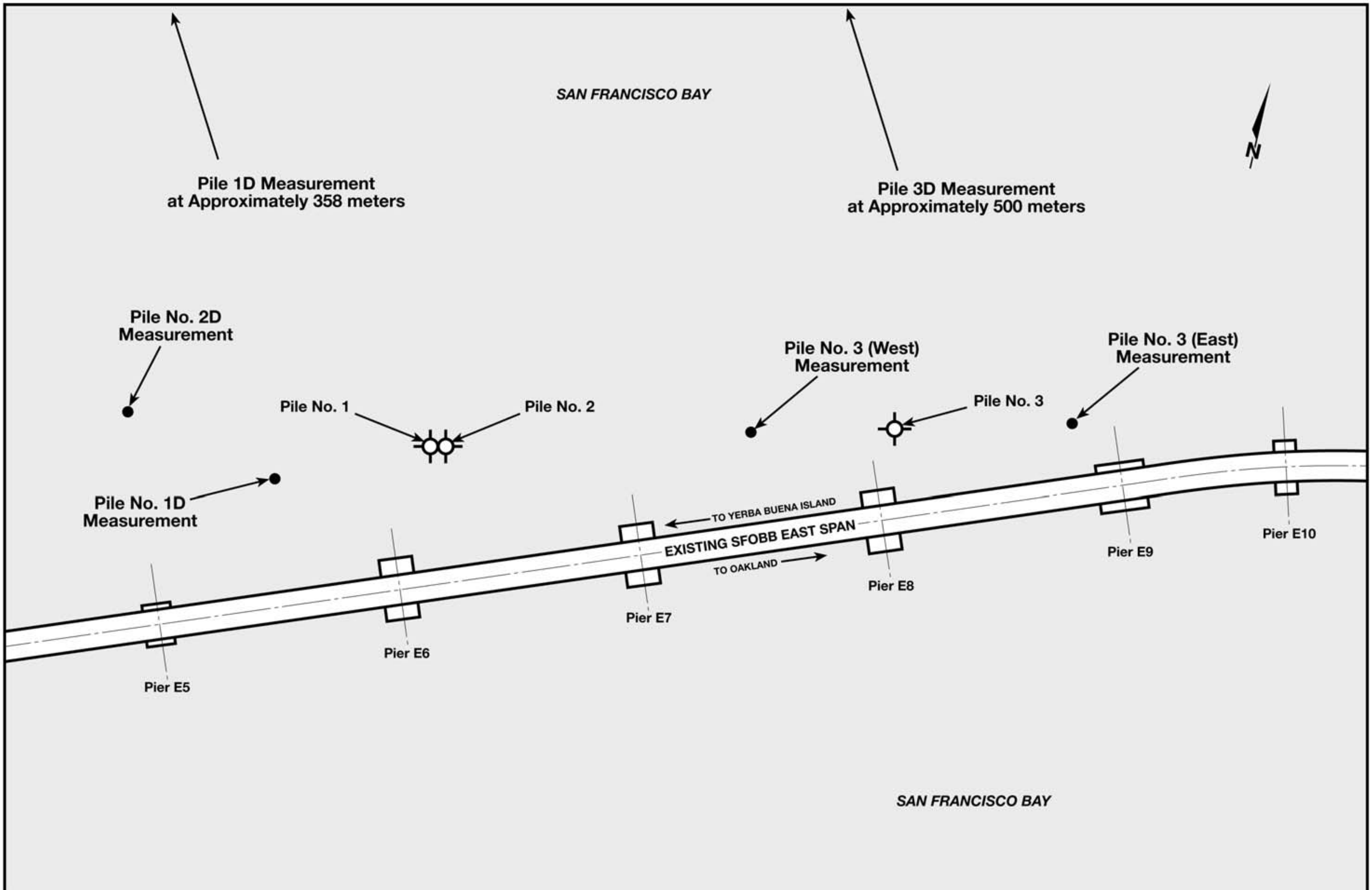

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GRAPHIC SCALE 1:3,500
0 100 200 300 m

Close-In Airborne and Underwater Noise Measurement Locations

Figure 2-4

7/20/01

3.0 PIDP MONITORING RESULTS

3.1 MARINE MAMMAL MONITORING

During the two-month PIDP construction period, 68 pinnipeds (55 harbor seals and 13 sea lions) were sighted within and around the established 500-meter (1,640-foot) safety zone of the construction site during marine mammal monitoring periods, which includes the minimum 30 minute pre- and post-driving monitoring time. Of the 68 pinnipeds sighted, only eight harbor seals and three sea lions were observed in the area surrounding the PIDP site during the actual pile-driving activity, which lasted less than 13 hours over the two-month project duration. In addition, up to 85 harbor seals per monitoring period hauled out at the semi-protected cove on the southwestern side of YBI, approximately 1,500 meters (4,920 feet) from the pile-driving area. At no time during the driving activities were gray whales observed surfacing or foraging in the areas monitored. Since PIDP construction activities were conducted before the gray whale migration period, from December to March, it is unlikely that these mammals were affected by the PIDP project. A summary of marine mammal observations is provided below.

3.1.1 Pre- and Post-Construction Observations

Marine mammal monitoring was conducted around the PIDP construction site for three days prior to the start of the PIDP construction from September 25-27, 2000 to understand pre-PIDP occurrence. Eleven harbor seals and two sea lions were seen during this time period: six harbor seals and one sea lion on September 25 from 7:00 a.m. to 4:00 p.m., two harbor seals on September 26 at approximately 7:00 a.m. and 1:00 p.m., and three harbor seals and one sea lion on September 27 between 10:45 a.m. and 2:45 p.m. These numbers are in addition to the 68 observed during the construction period. Activities included swimming, foraging and resting at the surface. Pinnipeds were identified when their heads came to the surface.

After construction was complete and equipment was removed, post-construction monitoring was conducted on December 19, 2000. Five harbor seals and one juvenile sea lion were observed between 9:45 a.m. and approximately 1:00 p.m. Activities of pinnipeds did not differ from pre-construction activities.

Marine mammal monitoring was also conducted at YBI for three days prior to the start of the PIDP construction. Data were collected over three tidal cycles. Observations began on October 9, 2000 at 11:30 a.m. during a high tide. During hide tide, harbor seals were typically in the water as very little shoreline was available on which to haul out at YBI. Catamarans, tugboats and aircraft typically caused head alerts from the harbor seals at the haul-out site, with an occasional flush (movement towards the water) due to helicopters or boats traveling too close to the shoreline. By the end of the observation period at 4:45 p.m., a maximum of 40 harbor seals had hauled out at YBI.

On October 10, 2000, seals were observed from 1:30 p.m. to 4:30 p.m. A maximum of 80 seals had hauled out by 4:00 p.m., and few disturbances to the harbor seals were observed. Pilot boats, a ferry and a helicopter caused only head alerts among the harbor seals gathered at the site.

Observations on October 11, 2000 were conducted from 11:45 a.m. to 3:45 p.m. A maximum of 30 seals had hauled out by the end of the monitoring session. A pilot boat and a low flying helicopter resulted in six and ten seals, respectively, diving below the water surface during a relatively high tide. Other disturbances, including a float plane and two helicopters, caused head alerts among the seals.

No monitoring data are available for YBI for post-construction monitoring.

3.1.2 Non-Pile Driving Conditions

Non-pile driving conditions are defined as those times before and after pile driving events. Observations at each of the two sites commenced at least 30 minutes before the pile driving began, and ended at a minimum of 30 minutes after cessation of pile driving. Occasionally, two or more pile driving events would take place per day, and observations were recorded during as well as between these times for any residual effects on marine mammals, with particular emphasis on harbor seals.

PIDP Construction Site
Observations at the PIDP construction site were only of those animals that raised their heads above the water surface the day of the pile driving. Typically, activities included swimming in and out of the preliminary 500-meter (1,640-foot) safety zone, diving and possible foraging. Occasionally, a seal investigated the barge or swam around the monitoring boat south of the barge, curious about the boat activities. A few seals appeared to be resting at the surface on the day Pile 2D was driven. Fifty-seven pinnipeds (47 harbor seals and 10 sea lions), of the 68 total different pinnipeds sighted during PIDP monitoring, were seen during non-pile driving activities.

Yerba Buena Island
Harbor seal response during non-pile driving conditions resembled that during the baseline conditions. High tides kept the seals from leaving the water for dry land. Aircraft, wakes from boats, and similar disturbances typically caused head alerts. During driving of Pile 1C on November 4, 2000, kayakers landing just west of the haul-out site caused all seals to flush the haul-out site. Similar behaviors were noted with other kayakers paddling close to the shoreline. On November 3, 2000, when Pile 2A was driven, several seals followed the kayaks for approximately 300 meters (984 feet) from the shore after they flushed 27 seals from the haul-out site. During driving of Pile 2D on November 19, 2000, a single kayak paddling 50 meters (164 feet) from the haul-out site resulted in flushing 38 of 41 seals. One seal trailed the kayaker for 200 meters (656 feet) as he departed the site. On November 11, 2000, two sailboats 300-400 meters (984-1312 feet) from shore caused all eight seals to flee the haul-out site and enter the water. This incident occurred after the re-driving of Pile 1D and was unrelated to the pile driving activity.

Other activities observed in the seals included flipper scratching and nipping among juveniles or adults, some infighting amongst the group and flipper slapping. These activities are associated with normal haul-out behaviors and are not related to human disturbance.

3.1.3 Pile Driving Conditions

Pile driving commenced on October 19, 2000 with the lowering, then driving of Pile 1 without sound attenuation. Pile 2 was driven with the protection of an air bubble curtain, and Pile 3 with the fabric barrier system with aerating mechanism. Two hammers were used to drive each of the four sections for each pile: the small (500 kJ) hammer was used to drive Sections A through C and the large (1,700 kJ) hammer was used to drive the final section and to redrive each pile to test sediment resistance. The small hammer was also used briefly to drive Section 2D. Marine mammals were observed at each survey area during scheduled pile driving. Over the approximately 13 hours of pile driving conducted during the PIDP, a total of eight harbor seals and three sea lions were observed. The following is a summary of marine mammal observations made during pile driving operations for each pile. Marine mammal behavior observed during pile driving using the small and large hammer is described.

Pile 1 Without Sound Attenuation

Two harbor seals and two seal lions were seen during pile driving operations at the PIDP construction site. Typically, seals were observed before or immediately after the noise of the construction activity, which included an additional total of 18 harbor seals and four sea lions. No reaction to the pile driving was observed at the YBI haul-out site with the exception of the first eight minutes of driving Pile 1A. During this eight-minute period, seals in the water ceased display behavior for a few minutes or responded with head alerts. Disruptions of the harbor seals at this study site typically occurred as the result of boat or aircraft activity. Behaviors ranged from head alerts to flushing when a number of kayaks came too close to or landed on the haul-out site during the Pile 1C driving event. Pile driving activities did not affect normal harbor seal behavior patterns at the haul-out site. Harbor seals continued to haul out during low tide and did not respond to pile driving either by head alerts or flushing.

<u>Small Hammer</u>

Only two harbor seals were observed during pile driving activities for Pile 1A through 1C at the PIDP construction site. The first seal was approximately 500 meters (1,640 feet) west of the barge at the beginning of pile driving for Pile 1A. The second was 450 meters (1,476 feet) northwest of the barge at the start of the driving for Pile 1C. No reaction from these harbor seals was observed. Although seals were observed no more than twice within minutes of the pile driving, construction could not be stopped moments before driving began due to logistical factors related to the hammer operation and speed of communication between monitors and the barge crew. These seals were not observed again after pile driving began.

One sea lion was also observed during the driving of Pile 1A. At the start of the second round of pile driving, the sea lion was observed moving out of the area. The mammal appeared to be affected by the construction activity as it was later seen to be swimming rapidly away from the pile-driving barge immediately after driving began.

Large Hammer

A sub-adult sea lion seemed to be affected on one occasion during the redriving of Pile 1D with the large hammer on November 11, 2000. The sea lion was observed just after the pile driving started south of the SFOBB near the edge of the established safety zone of 500 meters (1,640 feet). The sea lion began swimming rapidly west and porpoised away from the project site when the pile driving began. No harbor seals were observed during pile driving for Pile 1D.

Pile 2 With Air Bubble Curtain

Installation of Pile 2A began on November 3, 2000, before the installation of Pile 1 was completed. During driving of each section of Pile 2, the air bubble curtain was turned on during the first session of pile driving, then turned off for the second session to evaluate sound attenuation effectiveness. At most, three pile driving events of a single section occurred per day, with the air bubble curtain initially turned on and alternating between off and on during subsequent driving sessions. Twenty-three harbor seals and one sea lion were observed during the construction period, but only five harbor seals were seen during actual pile driving. Although seals were present at the YBI haul-out site during all pile driving sessions, no reaction (e.g., head alerts or flushing) were observed during the pile driving activity, regardless of the type of hammer used. During construction activity, the number of seals hauled out typically increased during periods of low tide, or decreased with an increasing tide level, which reduced the amount of haul-out space available. An unknown disturbance during the driving of Pile 2A did cause a number of mammals to flush; however, the occurrence is not believed to be related to the pile driving activity. A kayak paddling close to the site also caused a flushing disturbance, unrelated to the driving activity. Minor disturbances on YBI were caused by air and boat traffic or waves.

Small Hammer

At the PIDP construction site, two harbor seals were observed at the eastern edge of the 500 meter (1,640 foot) safety zone during the driving of Pile 2A. Neither of the seals seemed to react to the pile driving noise as they did not rapidly swim out of the area. Both remained at the surface for a few minutes before diving and swimming out of the area. A sea lion was observed briefly at the surface nearly an hour after pile driving ended.

During the driving of Pile 2B, one harbor seal was observed swimming northwest of the barge at the start of pile driving. The seal seemed to recognize the noise, as it kept looking toward the barge while swimming. However, the harbor seal did not seem alarmed by the construction activities. Another harbor seal was seen 500 meters (1,640 feet) west of the pile-driving barge 15 minutes after the start of the second session. Again, no reaction was noted as it continued to swim slowly north from its observed location.

Similarly, a harbor seal was observed shortly after the start of driving Pile 2C on November 15, 2000. Located approximately 400 meters (1,312 feet) northeast of Pier E8, the seal did not seem to be alarmed, but observed activities on the barge as it slowly swam out of the area.

Large Hammer

Driving of Pile 2D with the large hammer occurred over a two-day period from November 19 to 20, 2000. Disturbances observed at YBI were unrelated to the pile driving activities. Head alerts occurred in response to waves and helicopters; and the appearance of a kayaker within 50 meters (164 feet) of the shoreline flushed 38 out of 41 seals.

No harbor seals or California sea lions were observed in the area during any of the pile driving sessions at the PIDP construction site during the use of the large hammer on Pile 2D.

Pile 3 With Fabric Barrier System and Aerating Mechanism

Data from the driving of Pile 3, between December 1 and December 12, 2000, includes data on pile Sections 3B, 3C and 3D. Pile 3A was lowered to the sediment and sank through a sand lens under its own weight; therefore, no hammering was conducted. A total of twelve harbor seals and six sea lions were observed while monitors were present at Pile 3 during observations, but only one of each pinniped was observed during actual driving activity. During driving of Pile 3, the aerating mechanism in the fabric barrier system was turned on during the first driving session and alternately turned off and on during subsequent driving sessions. Marine mammal monitors were present at both YBI and at the PIDP construction site during driving of Pile 3. As with the previous two piles, there was no apparent reaction by harbor seals at the YBI haul-out site. During the driving of Pile 3C, the number of seals at the YBI haul-out site increased from one to 76 by the end of the observation period. Disturbances at YBI included tourists at the lighthouse and the wake of boats passing, which forced seals off rocks at the haul-out site. SFOBB vehicle traffic noise also caused some head alerts during this pile driving session.

Small Hammer

On December 3, 2000 during the driving of Pile 3B, one sea lion was observed at approximately 1,000 meters (3,280 feet) north of pier E6 in the vicinity of the PIDP construction site. Shortly after the start of the first driving session, the sea lion began swimming rapidly and continually porpoising away from the area. This behavior was observed on two other occasions with the small hammer in the PIDP construction site during driving activity.

During the driving of Pile 3C, soon after the start of the third driving session (when the aerating mechanism in the fabric barrier system was turned back on), one harbor seal was observed 200 meters (656 feet) southwest of the pile driving barge swimming toward the barge. In contrast to observed sea lion behavior, the seal did not appear to be alarmed by the noise. The seal resurfaced 150 meters (492 feet) off the west side of the barge moments later, and again did not show any reaction to the pile driving noise.

Large Hammer

Pile 3D was driven with the large, 1700 kJ hammer on December 11, 2000. Again, no apparent reaction was observed at the YBI haul-out site. A sea lion and two harbor seals were observed near the project area just before the pile driving began, delaying pile-driving activities temporarily. However, none of these mammals were present during the pile driving activities. On December 12, 2000 during the retap of Pile 3D, two sea lions were sighted 30 minutes before pile driving began. One harbor seal and one seal lion were observed from between 15 minutes to an hour after pile driving ceased. The sea lion was observed feeding on fish and diving in the area after pile driving stopped. This sea lion was one of only two sea lions observed during the monitoring period after pile driving ended for the entire two-month construction period. The other was seen after the driving of Pile 2A.

3.2 NOISE MEASUREMENTS

This section provides a summary of noise measurements conducted at Building 3 on Treasure Island, the USCG BEQ on YBI, and various locations near the pile-driving site (Figures 2-3 and 2-4). Airborne noise measurements at Building 3 on Treasure Island and at the USCG BEQ on YBI were conducted throughout the PIDP construction period and provide a conservative, worst-case estimate of noise levels at the YBI haul-out site. No sound measurements at the YBI haul-out site are available. These measurements were undertaken to understand potential human or land use disturbances during pile driving, and sound units are not comparable to close-in measurements for marine mammals. Ambient airborne noise would also be different at the distant and close-in locations and comparison of increases from these levels would be difficult. Underwater and airborne noise measurements close to the PIDP activities were conducted primarily during pile driving of the last section of each pile (Section D) when the large hammer was used. Airborne noise at the pile-driving site was also recorded for Pile 3C when the small hammer was used. Measurement terms used within this report are defined in detail in Appendix A.

3.2.1 Noise Measurements Prior to PIDP Construction

Airborne noise measurements were conducted at Building 3 on Treasure Island and at the USCG BEQ on YBI prior to the PIDP construction activity to determine baseline conditions. No preconstruction noise measurements were made at the pile-driving site.

Measurements of ambient conditions were made September 29 through October 2, 2000. Average airborne noise at Treasure Island, located approximately 1,500 meters (4,920 feet) from the PIDP site, ranged from 58-63 dBA re 20 μPa, with some noise reaching over 70 dBA re 20 μPa. Average airborne noise levels at the USCG BEQ on YBI, located approximately 1,200 to 1,500 meters (3,936 to 4,920 feet) from the PIDP site, ranged from 68-70 dBA re 20 μPa with the highest levels at 80 dBA re 20 μPa. Ambient noise sources included traffic on the SFOBB, traffic on local roadways, recreational or commercial boating activities and wind. Aircraft flying overhead produced the highest noise levels.

3.2.2 Noise Measurements During Pile Driving

Noise measurements at Building 3 on Treasure Island and at the USCG BEQ on YBI conducted during pile driving were similar to those recorded prior to PIDP construction activity. Airborne noise at these distances is not suspected to have influenced the behavior of the marine mammals due to the low or near ambient levels reported.

Therefore, this section focuses primarily on noise measurements near the PIDP site because the close-in noise levels were most likely to affect marine mammals.

Pile 1 Without Sound Attenuation

The driving of Pile 1 began on October 19 and was completed on November 11, 2000. Hammer energies ranged from 100 to 500 kJ with the small hammer and 1,000 to 1,300 kJ with the large hammer. No sound attenuation was used on this pile that was driven vertically into the Bay sea floor.

During driving of Pile 1D, measurements of airborne and underwater noise were made from a vessel in the Bay at two locations near the PIDP site, 103 meters (338 feet) west and 358 meters (1,174 feet) northwest of Pile 1. Airborne noise measurements were also made at an additional location approximately 350 meters (1,148 feet) east of the pile. As shown in Table 3-1, airborne linear peak measurements near the pile driving activities indicated noise levels of 120 dB re 20 μPa at 103 meters (338 feet) and about 100 dB re 20 μPa at 350-358 meters (1,148-1,174 feet).

The measurements of underwater SPLs were made at three depths: one, three, and six meters (3.3, 9.8 and 20 feet). At 103 meters (338 feet) from the pile, RMS (impulse) levels ranged from 185 dB at the one-meter (3.3-foot) depth to 196 dB at the six-meter (20-foot) depth (197-207 dB linear peak). At 358 meters (1,174 feet), RMS (impulse) levels were 17-18 dB less (167-179 dB) for the one- to six-meter (3- to 20-foot) depth interval (181-191 linear peak).

Table 3-1 Summary of Close-in Noise Measurements for Pile 1 Without Sound Attenuation

Location	Noise Levels (dB)	
	Pile 1A-1C[1]	Pile 1D[2]
Airborne[3]		
103 meters (338 feet) west of pile	n/a	120
358 meters (1,174 feet) northwest of pile	n/a	100
350 meters (1,148 feet) east of pile	n/a	101
Underwater[4]		
103 meters (338 feet) west of pile	n/a	185-196 RMS 197-207 LinPeak
358 meters (1,174 feet) west of pile	n/a	167-179 RMS 181-191 LinPeak

Source: Illingworth & Rodkin, 2001.
Notes: [1] Small hammer used for pile driving, with hammer energy 100-500kJ.
[2] Large hammer used for pile driving, with hammer energy 900-1,300kJ; RMS is RMS (impulse) per definitions, Appendix A.
[3] Airborne (linear peak) noise measurements are shown in dB re 20 μPa.
[4] Underwater noise measurements are shown in dB re 1 μPa.

Pile 2 With Air Bubble Curtain
Pile 2 was a battered pile angled to the east, or one that was driven in to the sediment on an angle of 1h:6v. Driving of Pile 2 began with Section A on November 3, 2000 and concluded with Section D on November 19 and November 20, 2000. An air bubble curtain surrounding this pile was tested during pile driving to determine its effectiveness in reducing SPLs.

Noise measurements near the PIDP activities were taken in air and underwater at 200 meters (656 feet) from the pile-driving barge. Section 2D was first driven with the small hammer on November 19, 2000, then driven with the large hammer on November 20, 2000; therefore, airborne and underwater noise levels were collected with both hammers for Pile 2D (Table 3-2).

<u>Small Hammer</u>
During driving of Pile 2D with the small hammer at maximum energy (500kJ), airborne noise measurements conducted at 200 meters (656 feet) from the PIDP activities reported linear peak levels of 110 dB re 20 μPa (Table 3-2).

Underwater noise measurements indicated that RMS (impulse) SPLs at 200 meters (656 feet) were 184 dB-189 dB at one- to six-meter (3.3- to 20-foot) depths. This corresponded to linear peak measurements of 197- 201 dB re 1 μPa at one- to six-meter (3.3- to 20-foot) depths.

Large Hammer

On November 20, 2000, Pile 2D was driven with the large hammer using a hammer energy between 900 and 1,000 kJ. Airborne noise measurements taken 200 meters (656 feet) from the pile indicated linear peak levels of 100 dB re 20 μPa (Table 3-2).

Underwater noise levels reported for the large hammer were similar to those reported for the small hammer, although energy levels were about twice that of the small hammer. Underwater noise measurements at 200 meters indicated 187-190 dB re 1 μPa at one- and six-meter (3.3- and 20 foot) depths for RMS (impulse) SPLs and 199-201 dB re 1 μPa for linear peak SPLs. These levels were less than or equal to three decibels (3 dB) higher than those recorded during driving with the small hammer.

Underwater SPLs during the driving of Pile 2D were measured 100 meters (328 feet) farther than during driving of Pile 1, yet similar SPLs were observed with the exception of the six-meter (20-foot) depth. At this depth, SPLs were 10 dB less for the small hammer and 8 dB less for the large hammer. Since sound waves spread spherically from the source, sound levels are expected to decrease by six dB in an unobstructed environment with a doubling of the distance with no extra attenuation (Appendix D). Apparently, excess attenuation was occurring at the deeper depths in the project area, but not at the shallower depths. These measurements seem to indicate a lack of attenuation using the air bubble curtain. Further discussion of underwater noise levels measured during driving of Pile 2 and their effects on marine mammals are provided in Section 4.1.2.

Table 3-2 Summary of Close-in Noise Measurements for Pile 2 with the Air Bubble Curtain

Location	Noise Levels (dB)	
	Pile 2D[1]	Pile 2D[2]
Airborne[3]		
200 meters (656 feet) west of pile	110 (for Pile 2D only)	109
Underwater[4]		
200 meters (656 feet) west of pile	184-189 RMS 197-201 LinPeak	187-190 RMS 199-201 LinPeak

Source: Illingworth & Rodkin, 2001.

Notes:
1 Small hammer used for pile driving, with hammer energy 100-500kJ.
2 Large hammer used for pile driving, with hammer energy 900-1,000kJ; RMS is RMS (impulse) per definitions, Appendix A.
3 Airborne (linear peak) noise measurements are shown in dB re 20 μPa.
4 Underwater noise measurements are shown in dB re 1 μPa.

Pile 3 With Fabric Barrier System and Aerating Mechanism

Pile 3 was driven as a battered pile to the west at an angle of 1h:6v, from December 1 to December 12, 2000. During driving of Pile 3, a proprietary fabric barrier system with aerating mechanism was tested to determine its effectiveness in reducing SPLs. The aerating mechanism contained in the fabric curtain that surrounded the pile was turned off and on during the pile driving activities to compare sound attenuation with the fabric curtain by itself and in conjunction with air bubbles. The fabric barrier system with aerating mechanism was operated during pile-driving for all segments, except Pile 3A which was lowered and descended into the Bay mud under its own weight.

Airborne SPLs were recorded at three distances for the driving of Pile 3C: 95 meters (312 feet) west, 110 meters (361 feet) east, and 350 meters (1,148 feet) to the north of the pile. During driving of Pile 3D, both airborne and underwater noise measurements were conducted near the PIDP driving activities at the following three distances: 95 meters (312 feet) west, 110 meters (361 feet) east, and 500 meters (1,640 feet) north of the pile. Underwater noise during the driving of Pile 3D was measured only at the 1-meter (3.3-foot) depth due to the cable length of hydrophone equipment used.

Noise measurements were conducted at similar distances east and west of the pile to compare differences in SPLs due to the direction of battered pile and the coverage of the fabric barrier system with aerating mechanism underwater. The air bubble and fabric barrier, which consisted of a fabric curtain of uniform height, had uneven contact with the Bay floor because the water depth in this area was approximately 7.5 meters (25 feet) on the west side of the pile and 5 meters (17 feet) deep on the east side of the pile. This resulted in a gap of 1.2-2.4 meters (4-8 feet) with tide conditions between the bottom of the curtain and the Bay floor on the west side due to scouring around pier E-8. Noise traveling through this gap was not attenuated.

Small Hammer

During driving of Pile 3C, linear peak airborne noise levels were reported at 101 dB re 20 μPa at 350 meters (1,148 feet) north, 115 dB re 20 μPa at 110 meters (361 feet) east, and 124 dB re 20 μPa at 95 meters (312 feet) west of the pile. Differences in SPLs at similar distances seemed to result from the battered angle of the pile (Table 3-3).

Large Hammer

During driving of Pile 3D, linear peak airborne noise levels were reported at 96 dB re 20 μPa at 500 meters (1,640 feet) north, 110-117 dB re 20 μPa at 110 meters (361 feet) east (with the aerating mechanism "on" and "off", respectively), and 124-125 dB re 20 μPa at 95 meters (312 feet) west (Table 3-3).

Underwater noise levels were also recorded at the same three distances from the pile-driving barge at a one-meter (3.3-foot) depth. At 95 meters (312 feet) west, RMS (impulse) levels ranged between 175 and 184 dB re 1 μPa (188 to 197 dB linear peak) with the aerating mechanism "on" or "off", respectively. Underwater RMS (impulse) levels at 110 meters (361 feet) east ranged between 172-175 dB re 1 μPa (186 to 189 dB linear peak) with the aerating mechanism "on" and 179 dB (193 dB linear peak) with the aerating mechanism "off".

The data suggest that air passing into the enclosed two-layer curtain had the effect of reducing noise by 4-7 dB. From these results, it also appears that the gap between the bottom of the fabric barrier system and the Bay floor resulted in higher measured noise levels to the west by approximately three to five dB.

Underwater noise was only recorded once at 500 meters (1,640 feet) north with RMS (impulse) levels of 160 dB re 1 μPa (170 dB linear peak).

Table 3-3 Summary of Close-in Noise Measurements for Pile 3 with the Fabric Barrier System with Aerating Mechanism

Location	Noise Levels (dB)	
	Pile 3C[1]	Pile 3D[2]
Airborne[3]		
110 meters (361 feet) east of pile	109-115 (for Pile 3C only)	110-117
95 meters (312 feet) west of pile	124 (for Pile 3C only)	124-125
350 meters (1,180 feet) north of pile	101 (for Pile 3C only)	96
Underwater[4]		
110 meters (361 feet) east of pile	n/a	172-175 (on), 179 (off) RMS; 186-189 (on), 193 (off) LinPeak
95 meters (312 feet) west of pile	n/a	175 (on), 184 (off) RMS; 188 (on), 197 (off) LinPeak
500 meters (1,640 feet) north of pile	n/a	160 (on) RMS; 170 (on) Lin Peak

Source: Illingworth & Rodkin, 2001.
Notes: [1] Small hammer used for pile driving, with hammer energy 200-500kJ.
[2] Large hammer used for pile driving, with hammer energy 900-1,600kJ; RMS is RMS (impulse) per definition, Appendix A.
[3] Airborne (linear peak) noise measurements are shown in dB re 20 μPa.
[4] Underwater noise measurements are shown in dB re 1 μPa.
n/a = not available.
on = Aerating mechanism turned on.
off = Aerating mechanism turned off.

4.0 IMPACTS ON MARINE MAMMALS

Research on marine mammals has shown behavior modifications and threshold shifts of hearing in response to noise (Richardson et al., 1995). Behavioral effects of loud noises of either short or long duration include permanently leaving the area (Allen, 1991), tissue rupturing or hemorrhaging at close ranges to the acoustic source, temporary or permanent hearing loss, swimming off course, abandoning habitats, and aggressive behavior (Kastak et al., 1999). Pup abandonment has also been noted in some species of pinnipeds when sound levels near breeding areas have caused adults to return to the water for up to 24 hours. General annoyance and helplessness from being denied a safe escape route have also been observed (Kastak and Schusterman, 1996). In addition, such noises can mask other sounds important to survival, such as those made by calves, mates or predators (Richardson et al., 1995; Allen, 1991).

Loss of hearing even temporarily, then, can have deleterious effects on marine mammals which depend on their hearing for echolocation, finding food, mating and breeding, and social activities (Kastak et al., 1999; Richardson et al., 1995). This section discusses the behaviors of marine mammals in the construction zone during the pile driving activities and the effectiveness of sound attenuation from the air bubble curtain and fabric barrier system with aerating mechanism on reducing SPLs from pile driving.

4.1 EFFECTS OF PILE DRIVING NOISE ON MARINE MAMMALS

A total of 68 individual pinnipeds were sighted during construction activities for the PIDP, which included 55 harbor seals and 13 sea lions. Eight individual harbor seals and three individual sea lions were observed in the PIDP construction site during the actual driving of Piles 1 through 3. Both species were observed before pile driving, but only harbor seals were observed post-driving, with the exception of two sea lions, one observed after Pile 2A was driven and the other post-tap of Pile 3D. Though these two species are related, they behaved differently in response to the pile driving noise and barge activities. The eight harbor seals seemed to observe the activities around the barge during pile driving, and did not show any avoidance response once the pile driving commenced. The three sea lions, on the other hand, rapidly swam and porpoised out of the area when pile driving began, indicating possibly: 1) increased sensitivity to the pile driving noise in air and/or water, 2) less conditioning to anthropogenic noise, or 3) a difference of the level of sound received by the sea lion resulting from varying human, environmental (ambient) and hammer magnitude or conditions at the time of pile driving. Alternatively, since the three sea lions were present at the start of pile driving, their response could indicate that they were startled by the noise (SRS Technologies, 2001). The frequency and duration of the noise and whether underwater or airborne sounds start suddenly or gradually, creating a ramping effect (as usually performed for the PIDP), may also influence the behavior of these mammals. However, none of these factors could be explored in detail within the scope of this demonstration project.

This section discusses the impacts of pile-driving noise on marine mammal activities and the effectiveness of the two sound attenuation devices on reducing SPLs. A discussion of the technical difficulties, and advantages/disadvantages of the two attenuation devices is provided in the conclusion (Section 6.0).

4.1.1 Pile 1 Without Sound Attenuation

Two harbor seals and two sea lions were observed near the PIDP site during the driving of Pile 1, including the redrive of 1D on November 11, 2000. However, only the two sea lions showed a reaction to the noise created by the pile driving.

Above Water
Responses to the pile driving noise varied from no reaction (harbor seals) to an avoidance response seen in the two sea lions. According to Kastak and Schusterman (1998) and Richardson et al., 1995), sea lions have a slightly greater sensitivity to airborne noise and higher high-frequency threshold than harbor seals at the sound frequencies typical for pile driving activities. Airborne noise from pile driving most likely played a part in startling the sea lions but had little effect on harbor seals. Since harbor seals have a lower detection threshold, it is possible that they were less sensitive to the noise of the hammer or were more conditioned to noise since they are more frequently present in the area.

Underwater
The two sea lions observed during driving of Pile 1 were identified at the edge of the preliminary safety zone of 500 meters (1,640 feet), where SPLs were likely below the 190 dB threshold based on noise measurements. However, a reaction by the sea lions was still observed. Kastak and Schusterman (1998) and Richardson et al. (1995) report that sea lions are more sensitive than harbor seals to underwater noise at low frequencies. This may indicate why a harbor seal observed swimming within the preliminary 500-meter (1,640-foot) safety zone during the pile driving activity with the small hammer did not show much response.

4.1.2 Pile 2 With Air Bubble Curtain

Five harbor seals but no sea lions were observed near the PIDP site during the driving of Pile 2 with the air bubble curtain. Periodically, the air bubble curtain was turned off during pile driving to test noise levels and response from mammals without sound attenuation. Based on the noise measurements conducted, no differences were readily apparent. More harbor seals were observed during the driving of Pile 2 than with any other pile; however, no sea lions were observed to make comparisons with the other two pile driving activities.

Above Water
During driving of Pile 2 with the air bubble curtain, harbor seals observed at the YBI haul-out site and near the PIDP area did not appear to be sensitive to airborne noise created by pile driving. Sound detection levels for harbor seals have been reported as low as 20 to 60 dB at 200 to 6400 Hz in air (Kastak and Schusterman, 1998; Richards et al., 1995).

Underwater
Harbor seals observed swimming within 500 meters (1,640 feet) of pile-driving activities did not seem to react to the underwater noise created. Seals merely continued to swim slowly out of the area. However, the operations from the pile driving activities appeared to draw attention from the harbor seals, as each seemed to watch the proceedings while traveling out of the area.

A direct comparison of underwater noise levels during driving of Piles 1 and 2 cannot be conducted since noise measurements were made at different distances. It can be noted, however, that SPLs at 200 meters (656 feet), at one- to three-meter (3.3- to 9.8-foot) depths, during driving of Pile 2 were only one to three dB lower than SPLs recorded at approximately 100 meters (328 feet) during driving of unattenuated Pile 1. A similar comparison of SPLs at the six–meter (20-foot) depth indicates that SPLs at 200 meters (656 feet) during driving of Pile 2 were up to 10 dB lower than at 100 meters (328 feet) during driving of unattenuated Pile 1. Normal sound travel is expected to decrease by six decibels with twice the distance with no attenuation (Appendix D).

The air bubble curtain SPL data indicated that there was no reduction in the overall linear sound level, the basis for the NMFS criterion level. However, the air bubble curtain was effective in reducing the SPL of frequencies greater than 800 Hz (Appendix D, Figure D-2, Noise Spectra). The shape of the impulse also changed with use of the air bubble curtain. An initial ramping or stair-step of SPLs is shown for the air bubble curtain and a spreading of the noise across the driving interval was observed, which resulted in a type of sound attenuation (Appendix D, Figures 9a-9c). Thus, though the magnitude of the SPLs did not indicate reduction except at deeper depths, noise was reduced at higher frequencies, and variation of the sound wave was seen with the air bubble curtain. These effects may have been important to the response of seals during the driving activities. Indeed, research has indicated that range of hearing for harbor seals and sea lions is 1 to 40 or 60 kHz, which includes frequencies of 800 Hz and higher previously noted (Kastak and Schusterman, 1998; Richards et al., 1995). Attenuation of SPLs using the air bubble curtain was effective at these levels.

Another explanation for the lack of difference in linear sound levels measured during driving of Piles 1 and 2 data is that strong currents and deeper depths were present during the driving of Pile 2. It is possible that the air bubble curtain is less effective at attenuation under these conditions (Appendix D).

The air bubble curtain has been used previously, during a study in which dolphins were monitored, with a reported 3-5 dB reduction in noise levels (Wursig et al., 2000). Similar to observed sea lion behavior during the PIDP study, the dolphins increased their travel speeds away from the pile driving activities, indicating that sound attenuation by the bubble screening did not completely eliminate all behavioral responses to the loud noise.

4.1.3 Pile 3 With Fabric Barrier System And Aerating Mechanism

Only one harbor seal and one sea lion were observed near the PIDP site during the pile driving activities for Pile 3. The aerating mechanism in the fabric barrier system was turned on and off during these pile-driving sessions to test the effectiveness of the fabric curtain alone in attenuating sound. The observed sea lion showed avoidance behavior by rapidly swimming away during the driving session. Another sea lion was seen in the area feeding on fish once the pile driving for the Pile 3D retap ended. This was one of two sea lions observed after pile driving ceased during the entire project (the other was observed after driving Pile 2A). The harbor seal showed no response.

Above Water
The behavior of harbor seals and sea lions observed during driving of Pile 3 were consistent with their behavior during driving of Pile 1. The fabric barrier system with aerating mechanism is a method of underwater sound attenuation and measurements of SPLs were made at similar distances to Pile 1. Airborne noise levels during driving of Pile 3 with the fabric barrier system with aerating mechanism were comparable to those during driving of Pile 1 without sound attenuation at similar distances.

Underwater
During driving of Pile 3C, a harbor seal observed swimming within 200 meters (656 feet) of the PIDP site did not appear to be affected by the noise from pile driving. However, a sea lion observed 1,000 meters (3,280 feet) from the barge responded by rapidly swimming out of the area during the driving of Pile 3B. This distance is well beyond the preliminary safety zone of 500 meters (1,640 feet). As previously noted, it would seem that harbor seals may be more conditioned to noise around the SFOBB than sea lions or that the sea lions were more startled by the noise caused by construction activities.

4.2 EFFECTS OF OTHER FACTORS ON MARINE MAMMALS

Noises from other sources, including disturbances from people on shore, wave activity created from passing ships, and kayakers paddling too close to the haul-out beach, caused head alerts or flushes at the YBI haul-out site. Tidal levels greatly influenced the numbers of seals hauled out on the beach, with lower numbers of animals observed during high tide. Pile-driving noise received at the YBI haul-out site was likely masked by the bridge, air, and boating traffic already occurring in the area, as was the case for sound measured at nearby locations to study human disturbance. The island itself also attenuates sound.

With the exception of the influence on sea lions by pile driving activity, boating, aircraft and recreational activity caused more reaction by marine mammals than construction activities at YBI. At the construction site, no external factors were noted influencing behavior other than PIDP activities.

4.3 ESTIMATED NUMBER OF MARINE MAMMALS HARASSED

4.3.1 Harbor Seals and Sea Lions

Harbor seals observed at the YBI haul-out site and near the construction area did not appear to be affected by pile driving during the PIDP.

Three sea lions were observed rapidly porpoising out of the area during pile driving for the project, which indicates they were affected by pile driving. As these mammals were observed on three separate days, during times in which both the small and large hammer were being used and sound attenuation devices were in operation, it does not appear that noise reductions reported of up to 10 dB in magnitude were a factor in sea lion behavior. In addition, a sea lion was affected during the use of the fabric barrier system with aerating mechanism at 1,000 meters (3,280 feet), which may indicate its ineffectiveness on reducing waterborne noise at frequencies important to sea lions. This sea lion was well out of the preliminary safety zone of 500 meters (1,640 feet), indicating that the attentuated pile driving sound remains at a magnitude that could startle some sea lions. No sea lions were observed during the driving of Pile 2 with the air bubble curtain; therefore the effect of this attenuation device on these mammals is unknown.

The frequency and duration of the sound could play a role in the effect of pile driving noise on marine mammal behavior. Longer driving of the piles which is expected for the East Span Project construction may cause, at minimum, leaving or temporary avoidance of the pile driving area by some pinnipeds during driving activity. The pile driving noise may also mask other underwater noises created by boats, aircraft (which can generate noise that travels underwater), or predators.

4.3.2 Gray Whales

No gray whales were observed during the PIDP project. However, gray whales can be expected in the Bay in increasing numbers during the months of December to March during their annual migration. Noise from the pile driving activities therefore may affect gray whales passing through the ship channel toward the southern San Bruno Shoals region. In contrast to seals, whales are more sensitive to high frequency noises, which are generated by pile driving activities (Richardson et al., 1995).

Behavioral responses of gray whales to noise can include avoidance, startle response, and complete abandonment of an area. Noise may elicit short-term disruptions of normal activities similar to seals, such as startle response, agitation, stress, and cessation of foraging activities. Most evidence suggests that whales will avoid loud noises, which may result in a temporary displacement of the animal from typical foraging or traveling areas.

5.0 MARINE MAMMAL SAFETY ZONES

Based on field measurements of underwater noise levels near the PIDP site, marine mammal safety zones were determined for Pile 1 without sound attenuation, Pile 2 with the air bubble curtain, and Pile 3 with the fabric barrier system with aerating mechanism. A detailed discussion of the calculation of the safety zones (190 dB contour re 1 μPa) is provided in Appendix D.

5.1 PILE 1 WITHOUT SOUND ATTENUATION

Field measurements of underwater noise during the driving of Pile 1D, with a hammer energy of 918 kJ, indicated that RMS (impulse) levels at 358 meters (1,174 feet) and a 6-meter (20-foot) depth were 179 dB re 1 μPa. RMS (impulse) levels at 103 meters (338 feet) and at the same depth were 196 dB re 1 μPa. These measurements corresponded to 191 dB and 207 dB linear peak sound levels.

SPLs could not be measured at all distances during pile driving; therefore, calculations were made to determine the 190 dB safety zone for different levels of hammer energy for an unattenuated pile. Based on available data, the safety zone was estimated to be 185 meters (607 feet) for 750 kJ of hammer energy and 285 meters (935 feet) for 1750 kJ, assuming no excess attenuation (Appendix D, Table 1).

5.2 PILE 2 WITH AIR BUBBLE CURTAIN

SPLs recorded at 200 meters (656 feet) from Pile 2 were not much different from those recorded about 100 meters (328 feet) from Pile 1. As described in Section 4.1.2, the air bubble curtain was effective at attenuating higher frequency noise and changed the shape of the impulse, which may be important to marine mammals. Based on the calculations of the safety zone for Pile 2, it was determined that the safety zone of 185-285 meters (607-935 feet) for 750 to 1750 kJ of hammer energy estimated for Pile 1 should be adequate to encompass the 190 dB contour re 1uPa (Appendix D, Table 2).

5.3 PILE 3 WITH FABRIC BARRIER SYSTEM AND AERATING MECHANISM

Underwater noise measurements indicated RMS (impulse) SPLs of 172-175 dB re 1 μPa at 95-110 meters (312-361 feet) during driving of Pile Section 3D with the aerating mechanism for the fabric barrier system with aerating mechanism turned on (186-189 dB linear peak). At the same distances, waterborne noise levels were only 4-9 dB higher with the aerating mechanism turned off; therefore, the 190 dB safety zone with just the floating curtain in place (no air bubbles traveling through the curtain) would also be less than 110 meters (361 feet). The fabric barrier system with aerating mechanism, which seemed to be effective at reducing SPLs, was calculated to require a safety zone of less than 100 meters (330 feet), a smaller safety zone than either that at Pile 1 or 2 (Appendix D, Table 2).

6.0 CONCLUSIONS

Sixty-eight sightings of marine mammals, which included harbor seals and sea lions, occurred during the marine mammal monitoring of the PIDP project. Only eleven of these sightings occurred during the actual pile driving activity (a period of less than 13 hours over two months). Based on marine mammal observations during the PIDP, harbor seals did not seem to be affected by pile driving for any of the three piles: Pile 1 without sound attenuation, Pile 2 with the air bubble curtain, and Pile 3 with the fabric barrier system with aerating mechanism. The three sea lions observed during pile driving seemed to be affected by the pile driving noise, as indicated by their swimming rapidly away from the area, while using either the unattenuated pile or the fabric barrier system with aerating mechanism. No sea lions were noted during driving of Pile 2 with the air bubble curtain.

Gray whales may be expected in the San Francisco Bay area during their migration season of December through March. It is not known from the PIDP results what their response may be to pile driving as no observations were made. Though their hearing is at higher frequencies than the majority of sound levels measured during driving activities, sound is generated in their hearing range. It is therefore likely that the mammals would avoid the pile driving area during construction for the East Span Project due to these higher frequency sound levels generated by pile driving, presence of equipment and consequent human disturbance (Richardson et al., 1995).
Field-measured SPLs indicated that the 190 dB contour re 1μPa varied, and would be between 100 and 350 meters (338 and 1,148 feet) without sound attenuation and approximately 100 meters (338 feet) with the fabric barrier system with aerating mechanism, depending on hammer energies. The fabric barrier system with aerating mechanism typically reduced SPLs by approximately 10 dB at 100 meters (338 feet) from the PIDP site compared to the unattenuated pile. Similar results could not be determined with the air bubble curtain based on available data. Although limited data from the air bubble curtain measurements did not indicate a reduction in the overall linear sound level (RMS [impulse] required by NMFS), it was effective at attenuating higher frequency noise of their hearing range and resulted in a change in the impulse shape. This may be just as important to marine mammals. Although it cannot be verified based on findings of this research, the higher frequency noise attenuation provided by the air bubble curtain is likely as beneficial to marine mammals as the overall linear sound level reductions provided by the fabric barrier system with aerating mechanism.

Since a limited number of marine mammals (eight harbor seals and three sea lions) were observed near the PIDP site during pile driving, it is difficult to draw conclusions about the impacts of noise on marine mammals and the effectiveness of the two sound attenuation devices in reducing those noise impacts. Although noise measurements indicate that the fabric barrier system with aerating mechanism was effective in reducing underwater noise levels up to 10 dB at 100 meters (361 feet) from the PIDP site, a sea lion was observing swimming rapidly away from the area at a distance of 1,000 meters (3,280 feet) even when this sound attenuation device was used.

Calculations of the 190 dB contour re 1uPa using measured noise levels indicate a safety zone of between 185 and 285 meters (607 and 935 feet) for the small and large hammer, respectively, for a pile driven without sound attenuation (Appendix D). These safety zones represent the worst-case, unattenuated scenario, with no excess attenuation. The calculated safety zones for a pile driven with the air bubble curtain pile were similar to those for the unattenuated pile, and were reduced to less than 100 meters (361 feet) for a pile with the fabric barrier system with aerating mechanism.

Use of the two sound attenuation systems on the PIDP provided information about the benefits and disadvantages of each. The air bubble curtain is effective and adaptable to a seafloor with either a sloping or flat bottom. As seen at the installation of Pile 2, the air bubble curtain has a disadvantage in that fast currents in deep water may divert the air bubbles at an angle thereby reducing the effectiveness of the curtain. However, even with strong currents during the PIDP, the bubbles always surrounded Pile 2. Assembly of the bubble ring must typically be done off-site where sufficient land area is available for construction. For repeated use during the proposed East Span Project, this system could be redesigned to better withstand the pressures of being repeatedly raised to the surface. When compared to the fabric barrier system with aerating mechanism, there would be a larger economy of scale if it were designed for multiple reuse. The air bubble curtain is advantageous in that it does not need to be attached to the pile template itself, and marine construction equipment can easily maneuver around and over the site without any hindrance from the air bubble curtain. Marine construction equipment does not appear to affect the operation of the bubble curtain. For reuse, the air bubble system's lack of bulk reduces the deployment logistics of relocating it to other pile locations. Once deployed, this system requires minimal inspection. With easier deployment, maneuverability, and minimal inspection, the chances for time consuming delays would likely be decreased. For the PIDP, the bid cost was $120,000 for one installation at Pile 2.

The fabric barrier system with aerating mechanism, used at Pile 3, would be most effective in an area where a flat bottom exists. Differences in bottom contour would result in a gap between the bottom of the curtain and the seafloor where sound would not be attenuated. For the proposed East Span Project, this system might be redesigned to be smaller for a single pile or much larger for a whole pier system. When compared with the air bubble curtain, there would be a smaller economy of scale if this system were designed for multiple reuse. Designing this system for reuse may include moving the template off-site, fitting different length curtains to it, and returning the refitted template back out to the project site. This could reduce the possibility of a gap between the bottom of the curtain and the sloping seafloor bottom. Costs would increase if the system needed to be redesigned for varying bottom elevations. Strain on the system from currents is less of a problem with this device than with the air bubble curtain alone, as the weight of the curtain typically keeps the system nearly vertical. For the PIDP, the fabric barrier system was attached to the pile template by the proprietor of the system. In future applications, this can be expected to be performed off-site. The bulkiness of this arrangement makes movement to the project site and movement between piles to be driven very difficult. The first attempt to deploy this system at the PIDP had to be postponed because in windy weather the curtain and template effectively acted as a sail. The height of this system and having it welded to the template also does not allow for easy maneuverability for the marine equipment. For example, a derrick barge cannot maneuver over it, and equipment on the barge must reach over the barrier to the pile being driven. Once deployed, this system requires inspection of the condition of the zippers in the fabric and the bottom alignment. Any damage to the fabric barrier system would likely require removing the template and barrier from the water to conduct repairs. This would cause time-consuming delays to the pile driving operations. For the PIDP, the bid plus change order cost was $580,000 for one installation at Pile 3. This included an additional bubble ring between the curtain and the pile, which was not in the project specifications, but likely aided in sound attenuation.

APPENDIX A
DEFINITIONS AND ACRONYMS

DEFINITIONS

A-weighted – The scale of pressure level that approximates the frequency response of a human ear when listening to every day activity (typically 1,000 to 5, 00o Hz).

dB – Decibel, a unit describing the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure of the sound measured to the reference pressure. The reference pressure for air and water is 20 μPa and 1 μPa, respectively.

dBA – The sound pressure level in decibels using the A-weighting filter network. This filter de-emphasizes the very low and very high frequency components of the sound in a manner similar to the frequency response of the human ear and correlates well with subjective reactions to noise.

Flush – Evacuation of a haul-out site and return to water by marine mammals.

Head Alert – Lifting head in response to disturbance exhibited by marine mammal

Hz – Hertz or frequency, cycles per second

Lin Peak – Linear Peak Level, unweighted peak sound pressure level based on the largest absolute value of the instantaneous sound pressure over the frequency range from 20 Hz to 20,000 Hz.

Lmax – Maximum RMS Noise Level, the maximum root-mean-square (RMS) sound pressure level during a measurement – measured using the "fast" exponential time constant. In this study, Lmax was typically 15-17 dB less than Lin Peak.

Pascal – A unit of pressure equal to one Newton per square meter

1μPa – Micro Pascal

RMS (impulse) - The maximum root-mean-square (RMS) sound pressure level measured averaged over a 31 milliseconds time frame (representing a 1/32 time constant). This value is the number used to determine the 190 dB contour re 1μPa and safety zones for NMFS. Previous studies conducted for NMFS have used a RMS pressure "averaged over the duration of the pulse" evaluated. In this study, most of the pulse energies occurred within the first 30 milliseconds. Averaging over a 31 millisecond time frame was a conservative estimate of the NMFS criterion as it averages the maximum sound pressure level over a shorter, but louder duration.

SPL – Sound Pressure Level. Sound pressure levels are expressed as a ratio between a measured level and a reference level of power per unit area.

Transducer – A device to convert underwater sound into electrical voltage

ACRONYMS

BEQ	Bachelor Enlisted Quarters
IHA	Incidental Harassment Authorization
MMPA	Marine Mammal Protection Act
MMSZ	Marine Mammal Safety Zone
NMFS	National Marine Fisheries Service
PIDP	Pile Installation Demonstration Project
SFOBB	San Francisco Oakland Bay Bridge
USCG	United States Coast Guard
YBI	Yerba Buena Island

APPENDIX B
REFERENCES

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APPENDIX C
INCIDENTAL HARASSMENT AUTHORIZATION (IHA)

APPENDIX D
SOUND MEASUREMENT UNITS DESCRIPTION AND 190 dB re 1 μPa SAFETY ZONE CONTOUR CALCULATIONS